THE EMPIRE JOURNAL OF EXPERIMENTAL AGRICULTURE

VOL. XXIX · NO. 116 · OCTOBER 1961

CONTENTS

D. N. Barua and K. N. Dutta: Root Growth of Cultivated Tea in the Presence of Shade Trees and Nitrogenous Manure . . . 287

J. Smartt: Factors Influencing the Selection and Performance of Groundnut Varieties in Northern Rhodesia 299

D. A. Lawes: Rainfall Conservation and the Yield of Cotton in Northern Nigeria 307

W. H. Foster: Note on the Establishment of a Legume in Rangeland in Northern Nigeria. With Plate 12 319

Alice M. Evans: The Yields of Eight Varieties of Sainfoin Cut at Different Growth Stages 323

E. B. Dennison: The Value of Farmyard Manure in Maintaining Fertility in Northern Nigeria 330

P. R. Hill: A Simple System of Management for Soil and Water Conservation and Drainage in Mechanized Crop Production in the Tropics. With Plates 13–19 337

B. Walker: An alternative to Flood Irrigation of Sugar Cane in British Guinea 350

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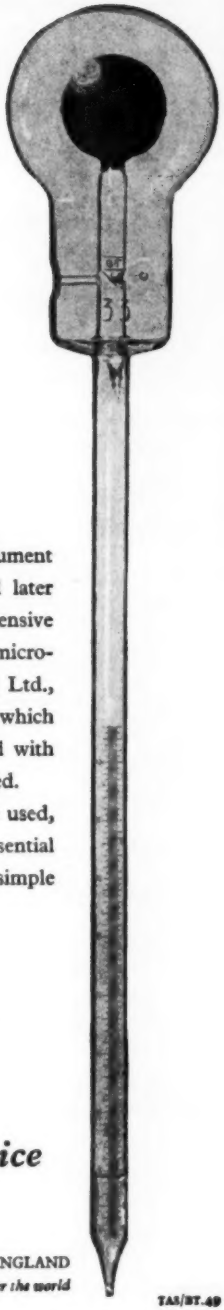

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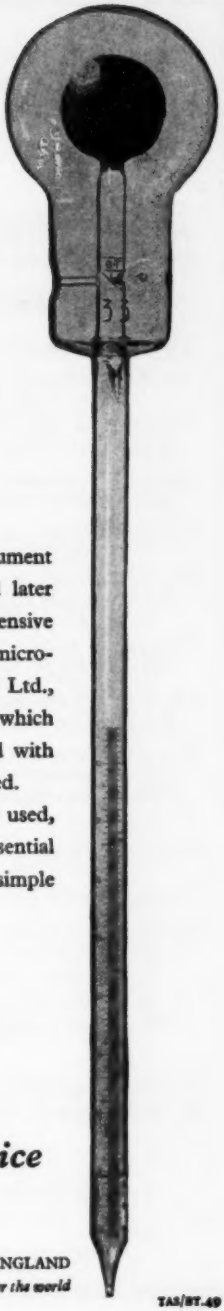

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CONTENTS of Volume 16. Number 2. June 1961.

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The relative palatability of various varieties of weeping lovegrass (*Eragrostis curvula* (Schrad) Nees). *J. H. Leigh*

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Selection and Breeding of the Coconut Palm. *A. E. Charles*

The Chemical Composition and Nutritive Value of Some Common Grasses in Uganda—I. General Pattern of Behaviour of Grasses. *R. M. Bredon and C. R. Horrell*

Studies on Pangola Grass at I.C.T.A., Trinidad—III. Concentrate Feeding for Dairy Cows on Pangola Grass Pastures. *M. H. Butterworth*

Forage Species in Northern Nigeria. *W. H. Foster and E. J. Mundy*

Observations on a Cross Breeding Experiment with Cattle in Nigeria. *J. Armour, R. P. Lee and J. G. Ross*

Responses of Cocoa to Copper Sprays in Ghana. *J. Bowden*

A Note on the Pruning of Amazon Cocoa in Ghana. *T. H. R. Hall*

Platynota rostrana (Walker): A Peel-feeding Pest of Bananas. *R. C. Bullock and F. S. Roberts*

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THE JOURNAL OF AGRICULTURAL SCIENCE

VOL. 57 PART 1 AUGUST 1961

Contents

RYLE, MARGARET. Early reproductive failure of ewes in a hot environment. I. Ovulation rate and embryonic mortality.

SLEE, J. and CARTER, H. B. A comparative study of fleece growth in Tasmanian Fine Merino and Wiltshire Horn ewes.

WIENER, GERALD. Population dynamics in fourteen lowland breeds of sheep in Great Britain.

WIDDOWSON, F. V., PENNY, A. and WILLIAMS, R. J. B. Experiments with nitrogen and potash on barley.

TODD, J. R. Magnesium in forage plants. II. Magnesium distribution in grasses and clovers.

LAMPKIN, G. H., HOWARD, D. A. and BURDIN, M. L. Studies on the production of beef from zebu cattle in East Africa. III. The value of feeding a phosphatic supplement.

ROBERTSON, I. S. The influence of turning on the hatchability of hens' eggs. I. The effect of rate of turning on hatchability. II. The effect of turning frequency on the pattern of mortality, the incidence of malpositions, malformations and dead embryos with no somatic abnormality.

CHAMBERS, D. T. Grass as a food for the calf. I. The value of cut grass in the diet of the unweaned calf in comparison with hay and concentrates. II. The effects of feeding grass or concentrates-with-hay during the pre-weaning period on the intake and utilization of grass during the post-weaning period.

BOLTON, W. The effects of supplemental detergents on the digestibility of poultry diets.

ALLEN, D. M. and LAMMING, G. E. Some effects of nutrition on the growth and sexual development of ewe lambs.

STORRY, J. E. Studies on calcium and magnesium in the alimentary tract of sheep. I. The distribution of calcium and magnesium in the contents taken from various parts of the alimentary tract. II. The effect of reducing the acidity of abomasal digesta *in vitro* on the distribution of calcium and magnesium.

EVANS, R. E. The protein-saving action of synthetic lysine and methionine.

CH'ANG, T. S. Reproductive performance of New Zealand Romney sheep grazed on red clover (*Trifolium pratense*) pastures.

ROBINSON, T. J. The time of ovulation and efficiency of fertilization following progesterone and pregnant mare serum treatment in the cyclic ewe.

LINDSAY, D. R. and ROBINSON, T. J. Studies on the efficiency of mating in the sheep. I. The effect of paddock size and number of rams. II. The effect of freedom of rams, paddock size, and age of ewes.

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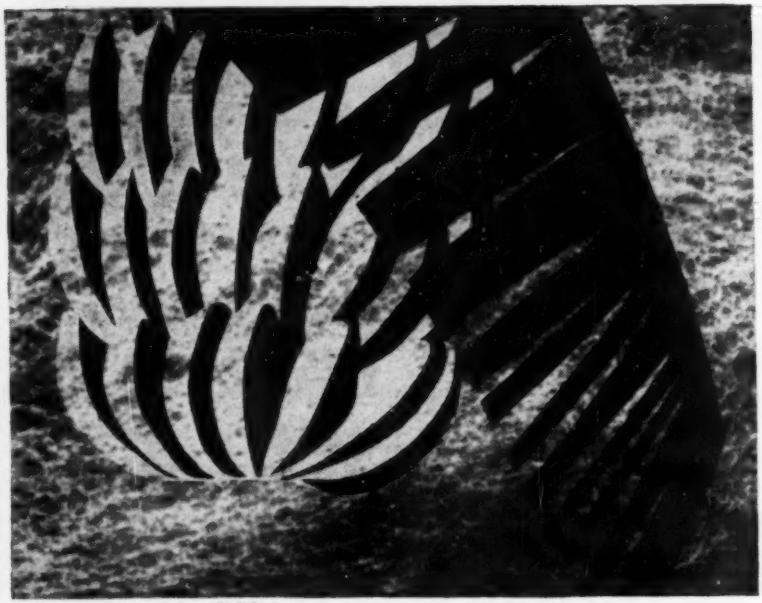

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ROOT GROWTH OF CULTIVATED TEA IN THE PRESENCE OF SHADE TREES AND NITROGENOUS MANURE

D. N. BARUA AND K. N. DUTTA

(*Tocklai Experimental Station, Indian Tea Association, Cinnamara, Assam*)

Summary

Length of the fibrous roots of the tea plant (*Camellia sinensis* L.) contained in soil cores drawn from ten depths between 0–70 cm., were measured every week for eighty successive weeks. Data for one complete year (52 weeks) are reported. The sampled rootlets were divided into white (feeding) and red (extension) portions. Red rootlets exceeding 3 mm. in diameter formed less than a thousandth part of the total length sampled and were not included in the analysis of the results.

Samples were drawn from four plots of eleven-year-old tea bushes in 1·37 m. triangular spacing, under four treatments: (1) Control, (2) Ammonium sulphate applied at 90 kg./ha.; (3) Canopy of *Albizzia chinensis* trees; and (4) A combination of (2) and (3). An approximate estimate of the sampling error was obtained by analysis of variance of the data grouped into four-weekly periods.

Lengths of white and red roots decreased exponentially with increasing sampling depth. The balance of white and red roots altered with depth and time of the year. Both white and red roots exhibited periodic growth, opposite in direction. Underlying these periodic fluctuations was a steady increase in the rates of regeneration and, presumably, decay during the main growing season from April to October. There was a reversal of these trends between December and March, the overall picture being that of a yearly cycle of growth and decay.

Treatments did not alter the yearly totals of red and white roots drawn from ten depths, but slightly altered the distribution in the top 10 cm. (two sampling depths) of soil. The major effect of treatment appears to be an alteration in the balance of feeding and extension roots at different times of the year. During the growing season, this balance was most favourable in the plot receiving ammonium sulphate under a canopy of *A. chinensis* trees. The highest crop yield was also obtained from the same plot, suggesting that the *A. chinensis* trees somehow increase the utilization of ammonium sulphate by tea roots.

QUANTITATIVE data on the feeder root growth of tea (*Camellia sinensis* L.) is limited to the observations of Eden [1] in Ceylon, Thomas [2] in Uganda, and Voroncov [3] in Russia. Eden and Thomas both recorded a very high concentration (above 70 per cent.) of fine roots in the top 30 cm. (12 in.) of soil. Voroncov observed fluctuations in the weight of active roots and changes in the proportion of dead to total roots at different times of the year. In India, previous work has been confined to the qualitative observations of Tunstall [4]. The present paper deals primarily with the nature and extent of seasonal variation and vertical distribution of the feeder root system of tea.

In India and Ceylon, the tea plant is usually cultivated under a shade-tree canopy. In the forms of tea plant most commonly cultivated in northern India, the yield of plucked shoots used in the manufacture of the commercial product is less with exposure to full sunlight than under shade trees [5]. Large amounts of nitrogenous manures are required to

[Empire Journ. of Exper. Agric., Vol. 29, No. 116, 1961.]

achieve a similar yield in full sunlight, ammonium sulphate being the most common source of nitrogen used in the tea industry. Cooper [5] found inorganic nitrogen (ammonium sulphate) to be of reduced efficiency under shade trees and this was borne out by subsequent investigations [6]. It was thought that the interaction of shade trees and nitrogen in respect of shoot growth might be reflected in the growth of the feeder roots. Root observations were planned to provide information on this aspect as well.

Nature of the Tea Roots

The youngest roots of the tea plant are white. As they get older the cells of the endodermis and the primary cortex become gradually suberized and the colour of the root changes to cream and finally to reddish-brown. The primary cortex shrivels and peels off in patches, exposing reddish-brown secondary bark.

Tunstall [4] found that the root hairs of tea were scanty and poorly developed, but the young roots were associated with a mycorrhizal fungus. Mycelia were present in the cells of the primary cortex throughout the length of the white- and cream-coloured portions of the root, except at the root tip. The mycelia disintegrated as the primary cortex ceased to function. These observations have been confirmed by the authors, who have supposed that the entire length of the white- and cream-coloured roots can absorb water and nutrients from the soil, although the capacity for absorption may diminish in the older cream-coloured regions. The white and cream parts of the fibrous root are, therefore, designated 'feeding roots' and the reddish-brown parts as 'extension roots', terms quoted by Rogers [7] in respect of apples.

Materials

The investigations have been made on a population raised from seed sold under a well-known registered trade name. Although our observations are therefore confined to a single 'jat' (cultivar) of tea, this is sufficiently representative to make the authors' conclusions of some general value. However, decidedly different jats are in cultivation and might react somewhat differently to shade trees and nitrogen supply.

Four plots of 100 bushes each, planted in 1·37-metre triangular spacing, were selected for observation. These plots were part of a larger experiment to study the yield and other responses of jats to shade-tree canopy and nitrogenous manuring. The experiment was designed by F. Yates of Rothamsted, and takes the form of partially confounded split plots, details of which are given by Wight and Barua [8].

Owing to the large amount of work involved in root sampling and measurement, observations were limited to one plot for each of the four treatments studied. These treatments were (i) control (no shade, no manure); (ii) shade-tree canopy (*Albizzia chinensis* (Osbeck) Merr. in 13·7 m. triangular spacing); (iii) nitrogen alone (90 kg./ha. annually, as ammonium sulphate, applied in the latter part of March); (iv) shade and nitrogen (treatments (ii) and (iii) combined). Although only one

plot of each treatment was used, it is considered that the particular plots observed can be taken as representative of the treatments since their yields were highly correlated ($r = 0{\cdot}97$, D.F. 2, $P < 0{\cdot}05$) with the mean yields for the same jat obtained for their respective treatments over the whole field experiment. Relative to control as 100, the mean treatment yields were: shade 184, nitrogen 223, shade and nitrogen 287; and were significantly different.

The shade trees were of the same age as the tea bushes. The mean light intensity under the *A. chinensis* canopy in the year of observation was of the order of 50 per cent. of that obtaining in full sun. This estimate was made with a Weston photo-electric meter at mid-day in June. The plots were pruned annually during November and the prunings returned to the soil as in normal practice. The bushes were plucked at weekly intervals to a flat table at a height of 20 cm. above the pruning level. Plucking began in April and continued until the middle of November. The bushes were 11 years old when root observations were started.

Cultivation of the experimental plots was confined to scraping the surface of the soil with hoes ('cheeling') once a month. The few weeds which grew under the tea bushes were cut in the cheeling operation and allowed to decay on the ground.

The experimental plots were on a sandy loam of the new Brahmaputra alluvium. Examination of the soil profile to a depth of 1 metre revealed a lighter surface zone of grey-brown colour, 17 to 23 cm. deep, and a lower compact zone of red-brown colour. The lower zone contains a higher percentage of clay and is more acid in reaction.

Sampling Method

The procedure for drawing root samples was that of Thomas [2] using a steel cylinder 38 mm. in diameter. The soil cores were soaked overnight in water and the soil particles washed away on a fine sieve. The tea roots were easily recognizable and were dipped in dilute formalin solution before being gummed end-to-end in lines on ruled paper; red and white rootlets were separated, creamy parts being included with the white. The white rootlets varied from 0·3 to 2·0 mm. in diameter and red rootlets from 1·0 to 3·0 mm. Roots exceeding 3·0 mm. in diameter were found to form less than a thousandth part of the total length sampled: they were considered to be part of the main scaffolding of the root system and were excluded from the calculations.

Each week one position in each plot was sampled at ten levels simultaneously, 0–2·5 cm., 7·5–10 cm., 15·0–17·5 cm., and so on to 67·5–70·0 cm. A set of eighty-one sampling positions, each equidistant from four neighbouring bushes, had been drawn up for each plot and one of these was drawn each week at random for sampling, subject to the proviso that no position was to be sampled twice until all eighty-one had been sampled once. Sampling continued from July 1947 until February 1949. The data for the fifty-two weekly samples of the year 1948 are considered in this paper.

Results

For want of repeats in space, the data do not permit of a proper assessment of the sampling error. By grouping the results for the fifty-two successive weeks into periods, however, it is possible by analysis of variance to separate the broad effects of season, kind of root, depth of sampling and their interactions, from the total variance, and so obtain a residual variance due to position plus interaction with precise time of

TABLE 1. *Analysis of Variance of the Lengths of White and Red Roots Grouped into four-weekly Periods*

Sources 2, 3, 5, 6, 7, and 11 are compared against 9, 10, 12, 13, 14, and 15, respectively; 4 is compared against the pooled variance of 9, 10, and 14, and 8 against that of 12, 13, and 15. The remaining seven sources of variation are compared against the residual. Significance at the $P = 0{\cdot}05$, $0{\cdot}01$, and $0{\cdot}001$ levels, is indicated by the signs *, †, and ‡ respectively.

Sources	*D.F.*	*M.S.*
1. Treatment (T) .	3	543·9
2. Depth (D) .	9	127,549·1‡
3. Kind of root (K)	1	143,240·3†
4. Period (P) . .	12	1,801·3
5. T×D . .	27	1,182·1‡
6. T×K . .	3	1,306·3
7. D×K . .	9	11,255·6‡
8. T×P . .	36	742·3
9. D×P . .	108	606·7‡
10. K×P . .	12	9,970·3‡
11. T×D×K . .	27	1,959·0
12. T×D×P . .	324	474·3*
13. T×K×P . .	36	1,076·9‡
14. D×K×P . .	108	1,476·3‡
15. T×D×K×P .	324	1,998·2‡
16. Residual . .	3,080	296·6
TOTAL . .	4,119	

sampling. In view of the representative nature of the experimental plots (see above, under *Materials*), it would not be unreasonable to regard such an estimate of the position variance within the plots as a rough estimate of the probable variance between plots due to position, and so to test whether the differences between treatments might be significant. Such an analysis can be utilized also for testing the significance of the other factors, viz. kind of root, vertical distribution, and seasonal variation, together with their interactions. Preliminary examination suggested grouping of the data into four-weekly periods, as six- and eight-weekly periods did not reduce the within-group variance to appreciably less than that of the four-weekly periods. For the purpose of analysis, the data for each treatment were accordingly grouped into thirteen four-weekly periods. The first and the last sampling dates of each period are shown in Table 4. Table 1 is the analysis of variance of the data.

Significance of the kind of root (K), depth of sampling (D), K × D and their interactions with treatment (T) are tested against their respective interaction of the next higher order with period (P), while the between-period variance (4) and its interaction with treatment (8) are compared against the pooled variances of (9), (10), and (14), and (12), (13), and (15), respectively. The remaining six sources of variation are tested against the residual.

Vertical Distribution

The average length of fibrous roots sampled from each of the ten depths during the fifty-two successive weeks decreased markedly with

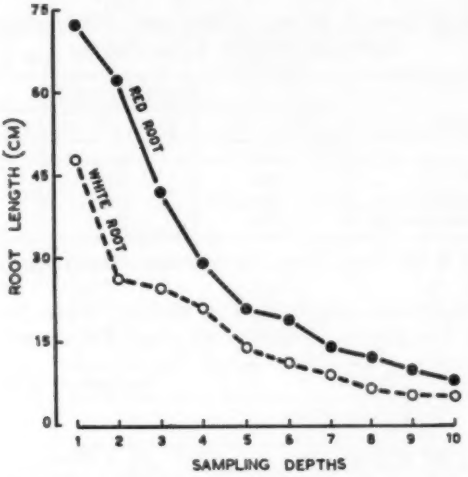

FIG. 1. Length of red and white roots per sample at successive sampling depths as mean of four treatments: (1) 0–2·5 cm., (2) 7·5–10·0 cm., (3) 15·0–17·5 cm., (4) 22·5–25·0 cm., (5) 30·0–32·5 cm., (6) 37·5–40·0 cm., (7) 45·0–47·5 cm., (8) 52·5–55·0 cm., (9) 60·0–62·5 cm., (10) 67·5–70·0 cm.

increasing depth: the length of roots at 67·5–70 cm. was approximately a tenth of that at 0–2·5 cm. Fig. 1 illustrates the vertical distribution of the red and white roots. Treatments did not significantly affect the total length of fibrous roots (Table 2) but altered the vertical distribution as shown by the significant T × D interaction of Table I. The significant part of the T × D interaction is confined to the top two depths of sampling, and this is shown in Table 3; the length of roots at the lower sampling depths remained unaffected by the treatments.

Considering the totals for the four treatments, the lengths of red and white roots sampled from the ten depths (K) and their differences at these depths (D × K) vary significantly (Table 2 and Fig. 1), but neither the lengths of white and red roots at successive depths nor their differences appear to be further affected by the treatments.

TABLE 2. *Average Total Length in cm. of Red and White Roots per Sample of Ten Depths*

Treatment	*Red*	*White*	*Red plus white*
Control	301	165	466
Nitrogen only	290	184	474
Shade tree canopy	296	157	453
Shade tree plus nitrogen	266	174	440
Mean	288	170	458
L.S.D. for means at $P = 0.05$	68		

TABLE 3. *Average Length in cm. of Red plus White Roots per Sample. Data for the Top Three Depths*

Treatment	*Depth of sampling*		
	0–2·5 cm.	*7·5–10·0 cm.*	*15·0–17·5 cm.*
Control	100	93	69
Nitrogen only	132	97	67
Shade tree canopy	129	86	64
Shade tree plus nitrogen	114	72	68

L.S.D. at $P = 0.05$: 12 cm. for treatment × depth interaction.

TABLE 4. *Average Total Length in cm. of Red and White Roots per Sample of Ten Depths. Mean of the Four Treatments*

	Period	*Root length in cm.*		
Serial no.	*Duration, showing the first and the last sampling dates*	*Red*	*White*	*Red plus white*
1.	2 Jan.–23 Jan.	296	127	423
2.	30 Jan.–20 Feb.	322	109	431
3.	27 Feb.–18 Mar.	296	104	400
4.	26 Mar.–16 Apr.	341	176	517
5.	22 Apr.–13 May	389	132	521
6.	20 May–10 June	358	132	490
7.	17 June–8 July	305	216	521
8.	15 July–5 Aug.	323	167	490
9.	12 Aug.–2 Sept.	326	158	484
10.	9 Sept.–30 Sept.	213	206	419
11.	7 Oct.–28 Oct.	179	164	343
12.	4 Nov.–25 Nov.	194	221	415
13.	2 Dec.–23 Dec.	166	279	445

Seasonal Variation

The total lengths of fibrous roots jointly and severally for all four treatments remained unchanged throughout the year (P and T × P), while the corresponding interactions with the red and white roots (K × P and T × K × P) changed along time. These latter results are shown respectively in Table 4 and Fig. 2.

The significance of the D × P and D × K × P interactions shows that the total lengths of red and white roots and their differences at successive depths did not remain constant throughout the year. The D × P interaction is illustrated by Fig. 3. Much importance cannot be attached to the T × D × P interaction because of its low level of significance. The non-significance of the T × D × K interaction shows that, considering in

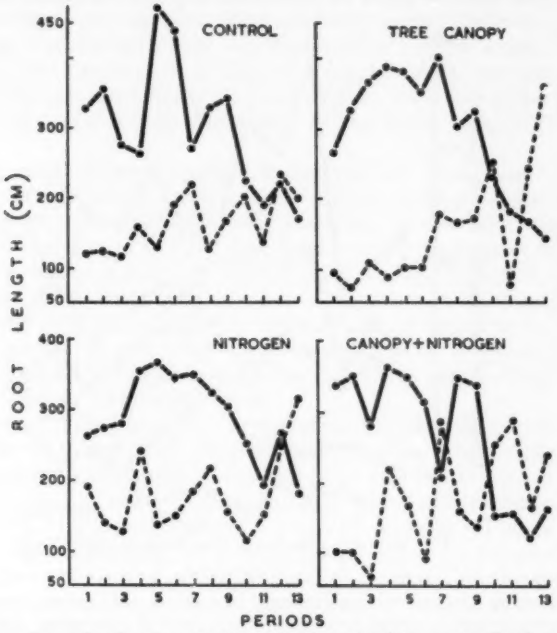

FIG. 2. Length of red roots (solid line) and white roots (broken line) per sample of ten depths at different periods of the year, beginning with January (period 1) and ending in December (period 13). The first and the last sampling dates of each period are given in Table 4. Root lengths shown separately for the four treatments—Control, Tree Canopy alone, Nitrogen only, and Tree Canopy plus Nitrogen.

terms of the totals for the whole year, the balance of red and white roots at different sampling depths was not altered by the treatments; the T × D × K interaction, however, varied between periods (T × D × K × P).

Discussion

The data presented in Fig. 1 show that more than 70 per cent. of the fibrous roots were confined to the top 30 cm. of soil. This is in complete agreement with the observations made in Ceylon [1] and Uganda [2]. The high water-table in the Assam plains presumably restricts development of deep roots. A tap root is virtually absent from most mature tea bushes, while in others it does not develop to any great extent. According

to Thomas [2] there is little development of a tap root in Uganda and Ceylon, where conditions are widely divergent from those obtaining in Assam. The close similarity of the results under diverse environmental conditions emphasizes the intrinsically shallow-rooting habit of tea, and indicates that cultivation should cause the minimum of disturbance to the surface layer of soil, where most of the feeding roots are concentrated.

In closely spaced plots of perennial tea, fibrous roots would, after a

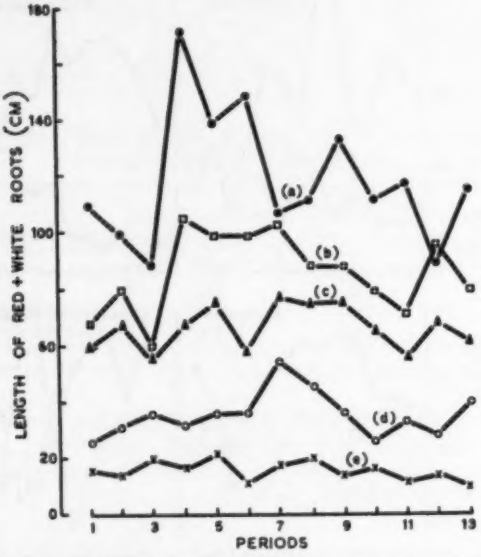

FIG. 3. Changes in the summated length of red plus white roots per sample, along time (periods), at five sampling depths: (*a*) 0–2·5 cm., (*b*) 7·5–10·0 cm., (*c*) 15·0–17·5 cm., (*d*) 30·0–32·5 cm., (*e*) 60·0–62·5 cm. For the first and the last sampling dates of each period see Table 4.

time, completely saturate the soil, at least in the zone of maximum root growth. Absence of significant differences in the total length of fibrous roots between the four treatments, and also between different times of the year (periods) is explicable from these considerations.

Rogers [7] compared the life of rootlets to that of leaves: once their absorbing function is over most rootlets cease to grow, and rot away. On this analogy, the fibrous roots can be supposed to remain in a state of dynamic equilibrium, regeneration compensating decay. One would, therefore, expect any difference which might have existed between treatments, depths, and seasons to show up in a shift in the balance of feeding and extension roots. The significant interactions between kinds of root and depth (K × D), and kinds of root and period (K × P) show that the balance of feeding and extension roots altered with depth of the root zone and time of the year.

There was a sharp drop in the proportion of feeding roots from 40 per cent. at 0–2·5 cm. to 30 per cent. at 7·5–10 cm. depth, which rose again to 42 per cent. at 22–25 cm. and remained fairly constant at 35–40 per cent. in the lower depths. The decline in the length of the feeding roots at the second sampling depth could be due to competition with the roots of weeds. Such competition even if it did exist at the surface layer (0–2·5 cm.) was possibly counteracted by the ample supply of nutrients from the decomposing vegetable litter normally found under tea bushes. Failure of the treatments to have significant effect on the annua balance of feeding and extension roots at different depths shows that the average rates of regeneration and decay at these depths were not influenced by the presence of deep-rooting shade trees or soil application of inorganic nitrogen.

The white roots showed a periodic rise and fall along time (Fig. 2), suggesting a periodicity of root growth similar to that of the tops [9, 10]. This aspect of root growth will, however, be discussed separately elsewhere. Periodicity of growth was observed also in respect of the red roots, but the growth periods of the red roots were opposite in direction to those of the white roots (Fig. 2); i.e. decrements in the length of red roots coincided with the increments in the length of white roots. Reduction in the length of red roots can be ascribed to death and decay. Regeneration thus becomes compensatory to decay supporting thereby the analogy between roots and leaves.

Despite periodic fluctuations, there was a steady increase in the length of white roots from the latter part of April till December, accompanied by a corresponding decrease in the length of red roots (Fig. 4). A reversal of the trend between December and April can be demonstrated by including in Fig. 4 two periods, 14 and 15 of 1949. This is done in Fig. 5. The figure suggests inversely related, annually repeated, cyclic changes in the amounts of white and red root, much of the latter presumably decaying in the course of time. Such a pattern is inevitable if root activity is to continue indefinitely in a restricted volume of soil, as it must necessarily do when a long-lived, shallow-rooted, perennial is planted so as fully to occupy the ground.

The tea plant is never entirely dormant, and under favourable conditions the top parts grow continuously. Activity, however, is periodic, and minimal top growth occurs in early January. It seems, therefore, that the general pattern of root growth bears some relation to the general pattern of top growth, and this matter will be explored in greater detail in a later paper. The results in this paper are in substantial agreement with those obtained in Russia by Voroncov [3] who observed a 12–13 per cent. reduction in the weight of active roots between December and February, this being more than made good by new roots at the end of March or in early April.

No difference was observed between treatments in respect of yearly totals of red and white roots, but the relative lengths of red and white roots at different times of the year were not the same for all the four treatments. This is shown by the significant $T \times K \times P$ interaction illustrated in Fig. 2. Thus an interaction between tree canopy and

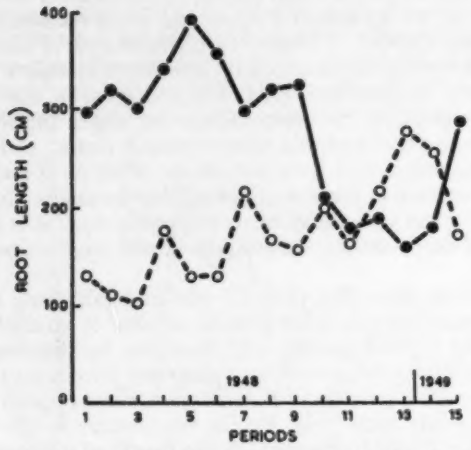

FIG. 4. Length of red roots (solid line) and white roots (broken line) per sample of ten depths at different times of the year, as means of four treatments. The first and the last dates of 1 to 13 periods are given in Table 4. Also included are the two periods 14 (27 Dec.–17 Jan.) and 15 (24 Jan.–14 Feb.) of 1949.

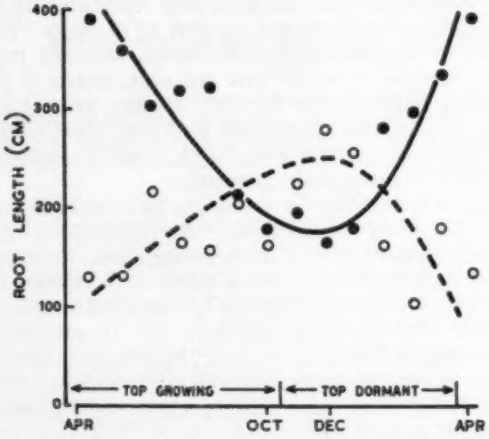

FIG. 5. Free-hand trends derived from Fig. 4 after rearrangement of the time scale. Mid-points of the months are marked. The expressions 'growing' and 'dormant' are used in a purely relative sense and apply to the aerial parts of the plant.

ammonium sulphate could be observed in the seasonal fluctuations of root growth. In north-east India the cropping (plucking) season lasts from April to October and a more or less dormant season commences in November. Considering the data in Fig. 2 in terms of these two seasons, ammonium sulphate caused the maximum production of white roots relative to red in the presence of *A. chinensis* trees during the growing season; but in full sun this happened during the dormant season (Table 5).

TABLE 5. *Excess of Red over White Roots per Sample of Ten Depths during the Cropping (April–October) and Dormant (November–March) Seasons; and Green Weight of Plucked Shoots, in kg. per 100 bushes, for the respective periods*

	Cropping season		*Dormant season*	
Treatment	*Excess of red over white roots (cm.)*	*Yield (kg.)*	*Excess of red over white roots (cm.)*	*Yield (kg.)*
Control . . .	119	48	110	4
Shade tree canopy .	174	103	75	12
Nitrogen only . .	142	112	48	8
Shade tree plus nitrogen	78	161	115	12

L.S.D. at $P = 0{\cdot}05$: 21 for treatment × kind of root × season interaction.

The excess of red over white roots in different treatments, either in the growing or in the dormant season, is not correlated with the yield in green weight of plucked shoots. In spite of a big difference in the balance of white and red roots, the yields of plots supplied with ammonium sulphate in full sun and grown under a tree canopy are almost identical (Table 5). Thus the interaction of shade trees with nitrogen in respect of crop yield [5] could not be associated with the balance of feeding and extension roots. However, the most favourable balance of feeding and extension roots during the growing season occurred in the plot receiving ammonium sulphate under a tree canopy, and this is the highest-yielding plot (Table 5). It seems, therefore, that some accessory factors due to *A. chinensis* trees are necessary for raising the capacity of the root system towards better utilization of ammonium sulphate. This does not agree with the traditional belief of tea planters [11] that shade trees, exemplified by *A. chinensis*, function mainly as a source of nitrogen.

Acknowledgements. The authors are indebted to the late Prof. E. J. Maskell for help with the statistical analysis of the data; to Dr. E. K. Woodford, now the Director, Unit of Experimental Agronomy, University of Oxford, for initiating the investigation of root growth at Tocklai in 1947; and to Dr. W. Wight for reading the manuscript. Thanks are also due to the Director of Tocklai, and the Indian Tea Association, for permission to publish.

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(*Received 5 August 1960*)

FACTORS INFLUENCING THE SELECTION AND PERFORMANCE OF GROUNDNUT VARIETIES IN NORTHERN RHODESIA

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Summary

In Northern Rhodesia it has been found important to obtain groundnut varieties of which the growing period to maturity coincides with the length of the growing season. Medium- and long-season varieties, of which the best so far tested is Mani Pintar, appear to be most suitable. In addition seed dormancy, disease resistance, growth habit, and kernel quality are also important.

In order to obtain maximum yields, sowing must be early and cultivation adequate. Lifting must be carried out at the correct time. Loss of yield and quality result from premature harvesting; delayed lifting, on the other hand, results in loss of yield through termite attack and the handling of the crop in a dry and brittle condition. Ridging, while recommended as an erosion control measure, and to facilitate harvesting, does not appear to increase yields *per se*. High plant population increases yield consistently, but continued investigation is necessary to determine optimum spacing within and between rows. Positive responses to fertilizers have been obtained, to ammonium sulphate at two of the five sites, and to phosphorus at one. It is not at present clear to what extent the response to ammonium sulphate is due to nitrogen or to sulphur.

In the plateau and valley regions of Northern Rhodesia at altitudes from 1,500 to 5,000 feet the rainfall varies from 20 to 60 in. per annum from the south to the north and north-east. The rainy season increases in length in the same direction, but all parts of the Territory have a marked dry season of at least five to six months from May to October. The population is low, mainly because of the poverty of the soils.

The best soils for general farming are reddish-brown clay loams, which are found in the Eastern, Southern, and Central Provinces. Groundnut production by Africans is already well established on such soils in the Eastern Province, but European farmers on similar soils in the Southern and Central Provinces have little interest in the crop, although its production could be considerably increased in these areas if problems of mechanization were solved. Yields obtained from groundnuts on other soils are unsatisfactory. In particular the highly leached soils of ancient origin present many difficult problems which may take a considerable time to solve.

The Basis of Variety Selection

Selection and breeding policy must take account of length of growing season, resistance to diseases, growth habit, and yielding capacity.

Length of Growing Season

Groundnut varieties exhibit a wide range in time to reach maturity (sowing to harvesting), from 120 to more than 160 days in the Lusaka

[Empire Journ. of Exper. Agric., Vol. 29, No. 116, 1961.]

area. Different areas require varieties of different season length, but in all cases experience and experiment show that groundnuts should be planted as early in the wet season as possible, when conditions favour more vigorous growth and establishment, leading to better final yields than with later plantings. However, if an early maturing variety such as Natal Common is planted early in the wet season it will mature when the ground is still moist and further rainfall can be expected. These varieties have no seed dormancy, so that mature seed will sprout in the pod, reducing the value of the crop. If it is planted late, so that the crop matures when the risk of sprouting is low, disease (especially rosette) may be most severe, while the late planting itself may lead to reduced yield. When a long-season variety is grown, without supplementary irrigation, in a shorter season, the yield will be low and the kernels shrivelled, immature, and poor in quality and oil content, giving when expressed a cake of lower protein content. Close adaptation of groundnut varieties to local season length is therefore most important.

Early maturing groundnut varieties do not seem to be suitable in those areas of Northern Rhodesia where the present production is greatest or where the prospects for the crop seem good. They are better suited to those parts of Southern Rhodesia and the Union of South Africa where lower wet-season mean temperatures and in some instances lower rainfall reduce the effective length of the growing season and increase the maturity period of groundnut varieties.

The varieties most suitable for Northern Rhodesia require a medium or long growing season. Preliminary experimental evidence indicates that towards the north and east long-season varieties are required, while in the Southern and Central Provinces the season is too short for these forms and varieties of medium season length are most suitable.

Disease resistance

The two most important diseases of groundnuts in Northern Rhodesia are the rosette virus and the leafspot diseases caused by species of Cercospora [1]. It is fortunate that the varieties most resistant to Cercospora are all medium- and long-season types. Varietal differences in degree of resistance to Cercospora have been observed locally as well as in East Africa [1, 2, 3]. Rosette is best controlled by the early sowing of sound seed at rates high enough to give a good cover of the ground, but in late seasons or where sowing is delayed, a variety resistant to the aphid vector or to the virus would offset the effects of heavy aphid attack and consequent spread of virus. A form of resistance to the spread of rosette disease has been found in the East African variety Asiriya Mwitunde [1, 4, 5] which also shows good leafspot resistance. Mwitunde is resistant to the spread of aphids rather than to the virus itself, and indeed Evans describes instances where this resistance has been swamped and heavy rosette infections have been established [4, 5]. A true virus resistance is claimed for certain varieties from French West Africa [6]. However, Mwitunde yields fairly well in Northern Rhodesia, whereas the other reputedly rosette-resistant types do not,

though they might be easier than Mwitunde to handle in a crossing programme.

Other diseases, such as the pod and kernel rots, are not serious at present as they can be controlled satisfactorily by cultural means.

Insect resistance

Apart from the possible resistance to aphid spread mentioned above, no differences in varietal resistance to insect pests have been found in groundnuts [cf. 7].

Quality

Groundnuts are sold either for confectionery or for oil expression, and a variety may not be equally well suited to both purposes. Confectionery varieties, which command the best prices, may have a lower oil content than oil varieties. These, on the other hand, are usually less suitable for the confectionery trade, in which uniformity in kernel size and palatability are the two most important requirements. Lack of uniformity in kernel size is a reflection of variability in size of pod and in the number of kernels per pod, which ranges in commonly cultivated varieties from two to four. Some varieties, such as Spanish, only rarely produce pods containing more than two kernels, but varieties of the Valencia and Matevere groups may have two, three, or four kernels per pod. Kernels from four-seeded pods tend to be smaller than those from two- and three-seeded pods. Further, there may be variation in kernel size within a single pod, particularly in Valencia varieties. Also late-produced pods usually have small or even shrivelled kernels, which in a dry season may form an appreciable proportion of the crop. Mechanical grading is useful, but in Valencia a sample of uniform size will still show some variation in shape.

The shape of a kernel depends on the number of kernels per pod and the presence or absence of pod constrictions between the kernels. Varieties with constricted pods, such as Spanish, have rounded kernels, while less-constricted forms (Natal, Valencia) have kernels with one or two flat contact faces. Thus, graded and screened kernels from Valencia and Spanish groundnuts would still differ in appeal to buyers, since kernels which are uniform in shape will be easier to process mechanically and will in addition have a more pleasing appearance.

Palatability is based on two attributes of the kernel. The flavour of the embryo tissue may be more or less pleasant or insipid, while the testa may have a bitter taste. Early varieties grown in the Lusaka area have on the whole rather more palatable kernels than late varieties, but the latter vary considerably in palatability and offer some scope for selection in consequence.

The value of a groundnut variety in the oil trade depends on oil content and oil quality, in that order. Varieties differ in oil content, and that of the kernels of a single variety will vary at different stages of maturity and in different localities [3].

Successive sampling at 10-day intervals showed that kernels of Asiriya Mwitunde increased in oil content from 36 per cent. at 120 days

from planting to 52 per cent. at 140 days. Comparisons of varieties must therefore be based on fully mature kernels. The protein content of the nuts increases with age: crude protein rose from 28 per cent. at 120 days to 33 per cent. at 140 days, and this difference will be reinforced in the press cake because of the greater proportion of oil in the mature nuts. These considerations demonstrate further the importance of using varieties which are able to mature satisfactorily in the length of season available.

Yielding Capacity

In the years 1956–9 a series of variety trials were conducted at the Central Agricultural Research Station, Mount Makulu. Material was collected from Rhodesia and from other countries, and after mechanical mixtures of forms had been separated in some varieties, selections were made for disease resistance, quality, and yield. The best of these were compared with a high-yielding but leafspot-susceptible variety.

The results are presented in Table 1. The season 1956–7 was excellent, 1957–8 was poor, and 1958–9 intermediate. Over the three seasons Mani Pintar consistently gave the best yield. The others varied in relative performance from season to season, but Giza Bunch/1 and S. 183 appear to be more consistent in performance and showed their superiority particularly in 1958–9. Giza Bunch/1 is susceptible to Cercospora.

TABLE 1. *Mean Yields (kernels lb./acre) of Groundnut Varieties, Mount Makulu 1956–9*

Variety	*Habit*	*Season*			*Variety mean yields*
		1956–7	*1957–8*	*1958–9*	*1956–9*
Mani Pintar . .	Bunch	2,192	1,011	1,472	1,558
S. 183 . . .	Runner	1,841	771	995	1,202
Giza Bunch/1 .	Bunch	1,738	846	1,095	1,168
Dixie Runner . .	Runner	1,621	938	404	988
B.S. 1. . . .	Runner	1,603	696	741	1,013
S. 731 . . .	Runner	1,589	950	736	1,092
Chitedze Mwitunde .	Bunch	1,512	631	630	924
TMV. 3 . .	Bunch	1,509	743	609	954
Asiriya Mwitunde .	Bunch	1,441	602	691	911
Seasonal mean yields . .		1,672	799	819	
Standard error of variety means .		±102	±49	±58	
Least significant differences, $P = 0.05$		299	158	190	

Mani Pintar has seed dormancy and the spreading bunch habit, matures in 140–150 days, which seems very suitable for the Southern and Central Provinces, and has some resistance to Cercospora. Unfortunately, its kernels are variegated red and white, but recently a red-seeded strain has been selected from it, and hybrids have been obtained with brown testas. Mani Pintar may have considerable influence on the future development of groundnut varieties in Northern Rhodesia.

There appears to be no very consistent or constant relationship between habit and yielding capacity. Some of the best and poorest yields in Table 1 are given by spreading bunch varieties, the yield of runner varieties being generally intermediate. Bunch forms are desirable for mechanization, but in less-advanced agricultural systems there are good reasons for retaining runner varieties.

Factors influencing Yield in Groundnuts

Fertilizers

On the Sudan clays groundnuts respond to nitrogenous fertilizers [8], while in East and West Africa phosphorus responses have sometimes been obtained [9, 10]. Sulphur seems to be important in some parts of Africa [10, 11], and potassium responses are known in sub-tropical areas [7]. Table 2 shows the results of five experiments conducted in various parts of the Territory in 1958–9. The only positive responses of any size were to nitrogen at three centres (significant at two) and to phosphorus at Misamfu (significant).

TABLE 2. *Responses of Groundnuts to Fertilizers, 1958–9 (kernels, lb./acre)*

Station	*Mount Makulu*	*Magoye*	*Masaiti*	*Petauke*	*Misamfu*
Province	*Central*	*Southern*	*Western*	*Eastern*	*Northern*
Variety	*Mani Pintar*	*Mwitunde*	*Local Runner*	*Local Runner*	*Mwitunde*
Effects (S.E.) .	(±37)	(±117)	(±138)	(±20)	(±22)
N[a] . .	142	−104	135	−87	200
P[b] . .	−133	27	85	−52	176
K[c] . .	−78	−12	−50	−17	54
Mean yield . .	1,760	1,351	602	862	804
Least significant effect, $P = 0{\cdot}05$	114	360	424	61	80

[a] response to 100 lb. ammonium sulphate per acre.
[b] response to 200 lb. single superphosphate per acre.
[c] response to 100 lb. muriate of potash per acre.

Bunting and Anderson [12] have reported that in Central Tanganyika a crop yielding over 900 lb. kernels per acre removed no more than 4 lb. of P per acre; the low requirement for phosphorus may perhaps explain the generally small responses to P in these experiments. In contrast the same dressing of superphosphate at Misamfu in 1958–9, on soya beans, increased yield from 428 to 1,035 lb. per acre. Potassium responses are unusual on tropical African soils and these particular results call for little comment. The nitrogen responses are not consistent throughout, but there is an indication that, on some soils at least, positive responses may occur.

Date of sowing

Experience has shown groundnuts (especially local varieties which are nearly all late-maturing) give their best yield and quality when sown

early in the season. In Nyasaland [13] larger yields are obtained from early maturing varieties when they are planted early. In practice, as already pointed out, early planting of early maturing varieties is not advisable on a large scale in Northern Rhodesia, because of the difficulty of drying the crop and the danger of losses through sprouting. The effect of sowing date on the yield of later-maturing varieties was studied in 1958–9 at three stations in the Territory (Table 3).

TABLE 3. *Effect of Time of Sowing on Yields of Groundnuts, 1958–9 (kernels, lb./acre)*

Station	*Mount Makulu*	*Ngoni Farm*	*Petauke*
Province	*Central*	*Eastern*	*Eastern*
Variety	*Mani Pintar*	*Local Runner*	*Virginia Bunch*
Sowing treatments (S.E.)	(±53)	(±40)	(±32)
1st sowing[a]	1,126	621	599
2nd sowing[a]	786	544	512
3rd sowing[a]	254	131	258
Least significant difference, $P = 0.05$	165	125	99

[a] 1st sowing immediately after onset of planting rains (late November); 2nd sowing two weeks later; 3rd sowing another two weeks later.

Later sowing reduced yield at all centres, and particularly at Mount Makulu where the season is shortest. Plot yields were rather more variable in later than in earlier plantings due to increasing and somewhat variable incidence of rosette disease.

Cultivations

In three experiments on cultivation in 1958–9 (Table 4), the crop was planted as soon as possible after ploughing and ridging. These operations gave a temporary initial control of weeds. Five cultivation

TABLE 4. *Effect of Number of Cultivations on the Yield of Groundnuts, 1958–9 (kernels, lb./acre)*

Station	*Mount Makulu*	*Ngoni Farm*	*Petauke*
Province	*Central*	*Eastern*	*Eastern*
Variety	*AS 1*	*Local Runner*	*Local Runner*
Number of cultivations (S.E.)	(±104)	(±61)	(±69)
0	137	228	63
1	278	468	489
2	1,053	762	440
3	1,162	936	599
4	1,489	980	651
5	1,467	893	600
Least significant difference, $P = 0.05$	313	189	214

treatments (ranging from one to five cultivations, the first being given within two weeks of emergence and the later ones at successive intervals of from two to four weeks thereafter) were compared with no weeding. In the absence of any weeding, yields were very low; all cultivation treatments increased yields, but the initial increase for a single cultivation was greater at Petauke than at the other two sites. Further cultivations increased yields up to the fourth, after which no further increase resulted. Clearly, the effects of any appreciable weed competition in the later stages of growth are quite considerable. This accords broadly with the conclusion of Bunting and Lea [8].

Time of lifting

Timely lifting is important in groundnuts, since premature lifting may prejudice yield and quality, and later lifting tends to favour losses from termite attack and the shattering of the dry and brittle plants. Experiments on this question are urgently needed in Northern Rhodesia, to determine the effect of altitude and rainfall régime on maturity date for the commonly grown varieties. Such information would also permit the prediction of maturity times of new varieties in different regions, from their performance at the Central Research Station. The information at present available suggests that at 4,000 feet above sea-level and under 30–35 in. mean annual rainfall, early maturing varieties require 120 days to mature, varieties with a medium length of growing season need 140–150 days, and those with a long growing season need about 160 days. At lower altitudes varieties mature more rapidly and at higher altitudes more slowly, but no precise measure of this effect is available. It probably depends largely on temperature.

Plant population

Plant population is an important factor in determining yield in groundnuts. High plant populations are also important for the control of rosette disease. Plant population and ridging practices were tested in three experiments in 1958–9. The levels of plant population per acre were 20,000, 40,000, and 80,000 plants in 2-foot rows. The four ridging treatments (sown on the flat; sown flat and then ridged; a single row sown on a narrow ridge; and two rows sown on a broad ridge) had no consistent effect on yield. In all the experiments (Table 5) yields tended to increase with increasing plant population up to the highest level used, but only one of the differences was significant (at Mount Makulu).

While these results suggest that high populations are advantageous, particularly in the spreading-bunch variety used, they do not cover the question of row spacing. Close rows appear to be important for disease and weed control, but they are not convenient for mechanical methods of production. Further, the effect of climate on optimum population and its arrangement are not known. Clearly more work is needed on these questions.

TABLE 5. *Effects of Ridging Methods and Plant Populations on the Yield of Groundnuts, 1958–9 (kernels, lb./acre)*

Station	*Mount Makulu*	*Ngoni Farm*	*Petauke*	
Province	*Central*	*Eastern*	*Eastern*	*Mean*
Variety	*Mani Pintar*	*Local Runner*	*Local Runner*	
Ridging treatments (S.E.)	(±74)[a]	(±54)[c]	(±40)[e]	
Flat	1,061	483	552	699
Flat and ridged	1,089	436	534	686
Narrow ridge	1,067	536	499	701
Broad ridge	1,094	576	525	732
Populations, thousands/acre	(±64)[b]	(±47)[d]	(±35)[f]	
20	955	461	491	636
40	1,103	505	515	708
80	1,175	560	576	770
Mean	1,078	509	527	

Least significant differences ($P = 0.05$)

a	b	c	d	e	f
230	199	169	149	107	126

Acknowledgements. The writer wishes to acknowledge gratefully the considerable assistance given by Professor A. H. Bunting in the preparation of this paper and the many useful suggestions made by A. Angus. The assistance of the Provincial staff of the Northern Rhodesia Department of Agriculture in carrying out field experiments is also gratefully acknowledged. Thanks are due to the Director of Agriculture, Northern Rhodesia, for permission to publish.

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(*Received 1 February 1960; as revised 6 October 1960*)

RAINFALL CONSERVATION AND THE YIELD OF COTTON IN NORTHERN NIGERIA

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Summary

The rainfall at Samaru in relation to the needs of the cotton crop, and the high proportion of the rain which may be lost by surface run-off, are discussed. The benefits to be derived from preventing run-off and improving infiltration are illustrated by yield data from a series of experiments over four seasons.

SAMARU is the Research Station of the Ministry of Agriculture of the Northern Region of Nigeria, and lies on latitude 11° 11′ N. and longitude 7° 38′ E., at 2,250 feet above sea-level. The average annual rainfall of 44 inches falls during the period May to October. Work on the inter-relationships between climate and crop growth commenced on cotton in 1956.

Five considerations suggested the need for such a study, viz.

General very low yields. The average yield of cotton grown by the native cultivator has been quoted as of the order of 150–200 lb. seed cotton per acre. The main reason for this extremely low yield level is late planting. To a certain extent this is excusable when poor rainfall distribution delays planting of the food crops, and so delays planting of cotton; but in many cases it can be ascribed only to general lack of a sense of urgency despite constant propaganda to promote early planting. However, even with early planting yields were low: a survey of trials up to 1940 by Ross [1] gave the average yield of cotton on Samaru experimental farm over a thirteen-year period as no more than 240 lb. seed cotton per acre, with a maximum of 426 lb. per acre. The mere substitution of other varieties, including earlier fruiting types [2], was found to promise no substantial improvement, though in recent years a rise to the level of 600–700 lb. per acre has followed the use of the new strains 'Samaru 26C' and '26J' in place of 'Allen', when combined with seed dressing against *Xanthomonas malvacearum* and with improvements in husbandry.

The low and inconsistent response to added nutrients. Even under conditions of early planting, the highest yields quoted in reports on fertilizer experiments rarely exceeded 600 lb. seed cotton per acre.

The low responses to insecticide applications. Even where these clearly reduced insect populations, responses were generally disappointing. In reports by Geering [3], Baillie & Geering [4], 833 lb. seed cotton per acre was the highest yield quoted and the general level with all insecticide treatments was much lower.

The 'seasonal effect'. The same strain of cotton planted in two seasons,

[Empire Journ. of Exper. Agric., Vol. 29, No. 116, 1961.]

given the same treatment throughout (time of planting, manuring, and husbandry), yielded twice as much in one season as the other.

Variability of yields within a field. In almost any year, in contrast with the low general level of yield, small patches of cotton could be found showing very much better growth and yield, such as could not be reproduced by manuring or application of fertilizers, nor easily explained by reference to mechanical or chemical analysis of the soil [5]. Small hollows tended to give very poor growth indeed while small mounds and accidentally extra-high ridges sometimes, but not always, gave better than average growth.

The first three of these considerations had led to the belief in some quarters that there was a 'ceiling' to cotton yields in Northern Nigeria, such that returns comparable to those obtained in other African territories were not to be expected with any variety or at any level of cultural treatment. The fourth suggested that this ceiling, although always present, rose and fell with seasonal differences in weather while the fifth indicated that soil conditions played some part in spite of the limited response obtained in fertilizer trials.

The weather, therefore, and in particular its most obviously variable feature, the rainfall, was the natural starting-point for a study aimed at raising and perhaps even removing altogether this supposed ceiling or barrier to good yields, with the additional clue hinting that soil texture and levels could be of considerable importance.

Rainfall Distribution

The average annual rainfall at Samaru, 44 inches, would appear at first glance to be more than adequate, but it was examined in terms of reliability by the method of Confidence Limits [6]. Mean rainfall figures and the 1 : 1 limits are given in Table 1. The lower limit of annual rainfall is 40 inches; this figure provides a more realistic total to work with, when considering the moisture likely to be available for crop growth.

The recommended date of planting of cotton, to fit in with a policy of giving priority to food crops whilst ensuring a good yield expectancy from the cotton, is 1 July. The lower 1 : 1 confidence limit of rainfall following this recommended date is 27·4 inches; in addition to this will be the available moisture already stored in the profile at the time of planting.

Crop Water Requirement

Estimates of crop water requirement, in terms of potential evapotranspiration, have been made by each of the following methods:

(*a*) 0·8 of the open water evaporation (Eo), as measured by a 6×6 ft. sunken tank.
(*b*) 0·8 of the open water evaporation (Eo), as calculated by the method of Penman [7].
(*c*) As calculated by the method of Thornthwaite [8].
(*d*) As calculated by the method of Thornthwaite as modified by Garnier [9].

Estimates of potential evapotranspiration by each of the above methods for the six months following planting are given in Table 2. For purposes of comparison all figures are the average of the three seasons 1957, 1958, and 1959; prior to this period there was no instrument available to measure wind speed as required for the Penman calculation.

TABLE 1. *Samaru Rainfall. Means and 1:1 Confidence Limits, in inches (28 years' data)*

Month	*Mean*	*Upper 1:1 limit*	*Lower 1:1 limit*
Jan.	0·0	0·0	0·0
Feb.	0·1	1·2	0·0
Mar.	0·4	1·7	0·0
Apr.	1·2	3·1	1·4
May	5·4	7·9	4·5
June	6·3	8·3	6·0
July	8·6	11·1	7·8
Aug.	11·8	14·8	10·4
Sept.	8·6	12·1	6·2
Oct.	1·4	3·0	1·4
Nov.	0·0	1·1	0·0
Dec.	0·0	0·0	0·0
Post-planting total (July onwards)	30·4	34·7	27·4
Annual total	43·8	48·8	40·0

TABLE 2. *Estimates of Potential Evapotranspiration at Samaru*

Method	*Monthly totals, inches*						*6-month total (in.)*
	July	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	
0·8 of Eo from tank	4·0	3·3	4·4	4·6	5·1	5·6	27·0
0·8 of the Penman estimate of Eo	4·5	4·1	4·3	5·1	4·3	4·2	26·5
Thornthwaite estimate	4·4	4·0	4·0	4·6	4·1	3·2	24·3
Garnier's modification of Thornthwaite estimate	3·7	3·5	3·7	4·4	5·0	5·4	25·7

All methods indicate that under the local conditions a crop of cotton requires about 25 inches of rainfall if soil moisture is not to be limiting to optimum growth.

Infiltration of Rainfall

The cultivated upland soils of Samaru and most of Zaria Province have been formed by an infilling of æolian drift on to a sedentary iron pan peneplain developed *in situ* from the underlying basement complex. This has resulted in fine sandy loams predominating, which may be 75 per cent. silt and fine sand. These soils 'cap' very readily under the pulverizing effect of heavy rainstorms, the surface becomes effectively sealed to infiltration, and run-off occurs [10].

Small-scale plots, designed to measure run-off under different surface

treatments, as reported by Lawes [11], have given results over several years. Some of these treatments are possibly of only academic value, whilst others are more practical and capable of being tried on field scale; descriptions of these are given later. The results from the small-scale plots over a period of two years are summarized in Table 3. This gives

TABLE 3. *Relative Efficiency of Soil Surface Treatments in Preventing Run-off of Rainfall*

Soil surface treatment	*Efficiency% of total rainfall penetrating soil surface (a)*	*Maximum infiltration rate: inches per hour (b)*
Bare soil		
Undisturbed . . .	31	0·5
Hoed at fortnightly intervals	49	0·9
Hoed after every storm .	57	1·2
Mulches		
Dead grass . . .	90	over 5 inches
Groundnut shells . .	89	over 5 inches
Sorghum stalks . .	98	over 5 inches
Laterite stones or granite chips	67	1·5
Layer of burnt soil . .	66	1·5

(*a*) Based on total rainfall over two years 1956 and 1957.
(*b*) Based on storms of peak intensity of over 5 inches per hour during period.

TABLE 4. *Soil Moisture at Various Depths at the Beginning and the End of the Rainy Season where Run-off has, and has not Occurred.*

Depth below surface (in.)	*Soil moisture (% oven-dry weight)*		
	Before rains	*After rains*	
		Run-off allowed	*Run-off prevented*
6	2·0	18·1	18·7
12	5·0	19·5	19·9
18	11·9	18·4	21·1
24	13·8	16·2	21·1
30	13·5	13·4	21·3
36	13·9	13·9	20·9
42	13·6	13·6	20·9
48	13·6	13·5	20·1

the efficiency of infiltration and the maximum infiltration rate in inches per hour, as calculated from the intensity of storms after the method of Hutchinson, Manning, and Farbrother [12].

Bare soil undisturbed may lose 70 per cent. of the total annual rainfall as run-off, and even with periodic surface cultivations the loss was 50 per cent. Unless this surface run-off is prevented, the rainfall available for crop usage is unlikely to be sufficient for optimum growth.

Table 4 gives figures for soil moisture at various depths on a site,

before the commencement of the rains. It also gives, for the same site, the soil moisture at the end of the rainy season under bare soil not disturbed, both where run-off has occurred unhindered and where run-off has been prevented by cross-tying. A total of 42 inches of rain fell between these two dates of sampling, yet where run-off had been allowed to occur, the soil at a depth of 30 inches was never wetted; the storage capacity of the profile was not utilized.

Conservation of Rainfall by Ridging and Cross-tying

In general, methods designed to conserve the soil also conserve rainfall, but whereas for the first a certain amount of run-off at a controlled rate may be allowed, for the second all the rain must be held on the land where it falls.

TABLE 5. *Yields of Seed Cotton in Experiments Comparing Open Furrows with Cross-tied Ridges during the three years 1956–8 (in the absence of measures to improve rainfall infiltration)*

Year	Total annual rainfall	Post-1 July rainfall	Open furrows		Tied ridges		% Increase or decrease with cross-tying
			lb./acre	%	lb./acre	%	
1956	36·5	27·4	628	100	718	114·3	+14·3±2·64
1957(*a*)	54·9	36·4	861	100	730	84·8	−15·2±2·73
(*b*)	..	..	807	100	705	87·3	−12·7±2·70
1958	35·0	22·7	720	100	878	122·0	+22·0±2·69

Ridging of the land is a practice widely used as a soil conservation measure in the rain-grown-crop areas of Africa, and has often been shown to give increased yields over cultivation on the flat [13]. As a further measure to ensure maximum retention of rainfall, the practice of tying the ridges together with small bunds at intervals may be carried out [14, 15, 16, 17, 18, 19]. Provided infiltration is adequate, the retention of rainfall will also improve aeration by the drainage of moisture down through the profile [20].

Ridging of the land is widely practised in Northern Nigeria; ridges put up by the native cultivators vary from 3 to 4 feet in width. The practice of 'tie ridging' has also been widely used [13, 16], although it is not so widespread now in Zaria Province as hitherto (Harberd, unpublished work, 1957).

At Samaru normal practice is to put up 3-foot ridges with either cattle or tractors, although for a few years, commencing with the advent of mechanization using unsuitable equipment, ridge size decreased to 2 ft. 6 in. on parts of the farm. All experiments discussed in this paper were carried out on 3-foot ridges.

Results of experiments carried out at Samaru during the period 1956–8, comparing cross-tied ridges with open furrows, are given in Table 5, along with the rainfall figures for those seasons.

These figures indicate that in seasons of below-average rainfall, cross-tying is beneficial, but in seasons of more-than-average rainfall the

benefit of moisture conservation is outweighed by the bad effects of standing water between the cross-ties during the height of the rains. This standing water prevents gaseous diffusion to and from the rooting zone and the partial asphyxiation depresses growth.

Field use of Treatments to Improve Rainfall Infiltration

Following up the evidence already presented, that certain soil-surface treatments can greatly improve the rate of infiltration by preventing the formation of a surface 'seal' or 'cap', field tests have been carried out using these treatments both as additions to cross-tying and as alternatives. In these experiments the effects of the treatments on soil moisture levels (determined both by the gravimetric method and by electrical resistance measurements) on crop growth (leaf area, plant height, &c.) and on yield have all been studied.

In 1956 heavy applications of groundnut shells as mulch were used on crops of sunflower and cotton. With sunflowers, mulching increased the weight of green plants from 6 to over 14 tons per acre, an increase of 138 per cent., and the weight of threshed seeds from 85 to 311 lb. per acre, an increase of 266 per cent. With cotton, the mulching increased the yield of seed cotton per acre from 485 to 646 lb., or 33 per cent. A fuller report of these experiments has already been published [11].

The rate of application of groundnut shells as mulch in these two experiments was extremely high (*c.* 25 tons per acre), the entire surface, ridges and furrows, being covered several inches deep. This rate of mulching is not practicable on a large scale, and later experiments, some of which have been reported briefly [21], have tested much lighter dressings, of the order of 4–5 tons per acre, in the furrow bottoms only. The ridges after being moulded were allowed to settle and wash with rain before the furrow bottoms were again broken up and the mulch applied. If spread in the newly made furrows, the mulch is buried by loose soil washed down from the ridges and is rendered ineffective.

In 1958 experiments combining mulching at this lighter rate with tying in various ways were carried out by using both groundnut shell and dead grass as the mulching material with ties in every furrow or in alternate furrows only. The results are set out in Table 6.

Both these experiments were given partial protection from damage by bollworms and stainers by two applications of an insecticidal dust, and this doubtless accounts in part for the good level of yields and also perhaps for the magnitude of the responses to the treatments.

The greater effect of groundnut shell mulch compared with dead-grass mulch, in increasing yield of seed cotton, as shown here, is in accordance with results obtained with other crops at Samaru. Measurements of soil moisture were taken during the season and the figures show that the soil moisture under alternately tied ridges was almost identical with that under tied ridges, both being near field capacity throughout the growing season, whereas that under the open furrows was at a lower level. The additional rainfall conserved by tying all ridges as compared with tying alternate ones was surplus to requirement and drained down past the depth of rooting.

TABLE 6. *Yields of Seed Cotton from Various Combinations of Mulching and Cross-tying*

Treatment	*Yield*	
	lb./acre	*% of control*
Expt. I. *Groundnut shell as the mulching material*		
All furrows open and unmulched	795	100·0
Alternate furrows open and unmulched	1,048	132·2
Tied and mulched throughout	1,035	130·5
S.E.	±47·4	±5·99
Expt. II. *Dead grass as mulching material*		
All furrows open and unmulched	785	100·0
Alternate furrows open and unmulched	922	117·4
Tied and mulched throughout	924	117·8
S.E.	±40·4	±5·15

TABLE 7. *Yields of Seed Cotton from an Experiment Comparing Different Types of Mulch at Three Levels of Nitrogen*

Treatments	*Yield*	
	lb./acre	*% of control*
Mulch	*Means for all levels of N*	
None	1,287	100·0
Dead grass	1,303	101·2
Chopped sorghum stalks	1,399	108·7
Groundnut shell	1,319	102·5
Coarse sawdust and wood shavings	1,305	101·4
S.E.	±17·2	±1·34
Nitrogen	*Means for all mulch treatments*	
None	1,128	100·0
94 lb. amm. sulph. at planting	1,381	122·4
94 lb. amm. sulph. at planting and a further 94 lb. six weeks later	1,461	129·5
S.E.	±63·9	±5·66

In a third experiment all furrows whether tied or open were mulched with dead grass. The yields of seed cotton were 1,057 and 1,109 lb. per acre (S.E.±35·3) with tied and open furrows respectively. There was thus no significant difference between the two treatments; by using a mulch sufficient rainfall was retained without putting up cross-ties.

In a fourth experiment, five mulching treatments were compared at three levels of nitrogen, the ridges being cross-tied throughout. The whole experiment received single superphosphate at the rate of 124 lb. per acre and was sprayed with insecticides seven times at weekly intervals from 9 September.

The results are given in Table 7.

Little response to the light applications of mulch was obtained. By

cross-tying the ridges all the rainfall was held on the soil and in this season there were no deleterious effects of water standing on the surface where there was no mulch (see comments on Table 5). One application of nitrogen increased yields appreciably, but there was less response to the second dose. There was no significant interaction between mulches and levels of nitrogen. Spraying with insecticides was carried out to keep insect attack to a minimum. With this type of experiment where different treatments causing different levels of plant growth are tested, preferential attack by insects may nullify or even reverse the effects of treatment differences on yield.

TABLE 8. *Yields of Seed Cotton from an Experiment Testing 'Vertical Mulching'*

Treatment	*Yield*	
	lb./acre	*% of control*
Normal furrows . .	1,026	100·0
Groundnut shell mulch (very light dressing) .	1,082	105·5
Furrow bottom slit .	1,052	102·6
Vertical mulched . .	1,248	121·7
S.E. . . .	±58·1	±5·67

Another measure calculated to improve infiltration at least temporarily, and hence conserve some rain even in the absence of cross-ties, is to slit open the furrow bottom with a suitable implement. In a first trial of this in 1958 a slit about 14 inches deep was made with a tractor-mounted tine five weeks after planting. Subsequent rainfall totalled 17 inches. The immediate effect of this slit was easily observable after a rainstorm and was confirmed by measurement, but the operation was not repeated and, as might be expected, subsequent heavy rain silted up the fissure and the visible difference between treated and control furrows progressively diminished.

Nevertheless, this one operation resulted in observable differences in plant size and a significant difference in the yields, which were respectively 925 and 864 lb. per acre with and without slit furrows (S.E.±13·6).

In 1959 a further experiment was carried out testing the technique of 'vertical mulching', whereby the slit was made to a depth of 10 inches, once during the season and was prevented from silting up by filling it with a mulch of groundnut shells. The operation was carried out at the time of planting. The whole experiment was cross-tied; the results are given in Table 8.

Further experimentation is required to investigate whether such a deep operation is necessary; a much shallower slit might be equally effective.

Time of Land Preparation

For the last ten years it has been the policy of the Cotton Section at Samaru to ridge and cross-tie the land for cotton as early in the season as possible. Land preparation is governed by the arrival of the rains; the

earliest date possible is usually in May. Native practice, on the other hand, is to leave the preparation of land for cotton until just before planting, *i.e.* until the end of June, if the recommendation to plant on 1 July is being followed.

Two experiments were carried out during 1958 to compare these two dates of land preparation. The results are given in Table 9.

TABLE 9. *Yields of Seed Cotton from two Experiments Comparing Early and Late Preparation of the Land before Planting*

Experiment no.	*Time of land preparation*	*Yield*	
		lb./acre	*% of control*
I	1 May	973	114·7
	27 June	848	100·0
	S.E.	±17·5	±2·07
II	1 May	683	125·1
	27 June	546	100·0
	S.E.	±19·8	±3·62

The superiority of early preparation is attributed to three separate effects. First, the improved water infiltration into the stirred soil, and the action of the cross-ties in preventing any run-off of early rains, build up soil moisture needed for rapid germination and good early growth. Secondly, early weed growth is substantially checked and the removal of water and nutrients by weeds is much reduced (the local practice is in effect to grow two crops in succession, the first being a heavy crop of weeds). Thirdly, the early opening up of the soil and improved entry of water must affect the microbiological activity and nitrogen cycle. It is considered that, on balance, the changes so caused are likely to be favourable to the young cotton crop which is to follow.

Recent Developments of Cross-tying Technique

In 1959, following up the result of the experiment in 1958 which showed that the tying of every ridge gave no improvement over tying alternate ridges, in a year when every drop of rain might be thought necessary (total rainfall 35 inches, post-planting rainfall 23 inches), the technique of cross-tying only alternate ridges was again tested, together with the removal of the cross-ties at the height of the rains.

Results are given in Table 10.

Rainfall distribution was such that at times there was standing water where ridges were cross-tied; in consequence the tying of every furrow throughout the season resulted in a decrease in yield compared with open furrows. Ties across alternate furrows avoided this bad effect, as also did the tying of every ridge, but only until the rains were likely to become excessive. Both these treatments gave substantial increases compared with the yields from completely open furrows.

These appear to be practical methods of reaping a good part of the benefit of rainfall conservation by cross-tying, without risking the bad effects suffered in some seasons when complete tying is practised on

soils of poor infiltration, until practicable methods can be devised which will both conserve, and obtain rapid infiltration of all the rainfall.

Responses at Higher Fertility Levels

All the rainfall-conservation experiments described above have been carried out at low and medium levels of fertility; the responses obtained show that at those levels soil moisture is often a limiting factor to crop growth. It follows that, in so far as measures to raise the soil fertility fail to increase soil moisture, or to reduce the water requirements of the crop, they are unlikely to improve yields substantially.

TABLE 10. *Yields of Seed Cotton with Various Forms of Cross-tying*

Treatment	*Yield*	
	lb./acre	*% of control*
All furrows left open . .	576	100·0
Alternate furrows left open .	638	110·8
All ridges tied but ties removed at height of rains . .	640	111·1
All ridges tied throughout the season	541	93·9
S.E.	±20·1	±3·48

Conversely, using effective conservation measures, and with moisture no longer limiting, responses not previously obtained should follow the raising of fertility level and the application of insecticides.

To find out what yield of seed cotton per acre is possible at Samaru, after measures have been taken to ensure rainfall conservation, more rapid infiltration and improved aeration, heavily manured crops have been grown for three successive years, giving them all treatments which from present knowledge are thought to be beneficial. Extra care was taken to see that thinning was done early and the whole plot kept clean-weeded. The furrow bottoms were kept 'open' by hoeing as necessary before mulch was applied, so that throughout all seasons there was never standing water in the furrows for any length of time. The same half-acre of land, which was known already to be in good heart, has been used each year. Details of the treatments are given in Table 11, along with the post-planting rainfall and the yields of seed cotton obtained.

The rainfall patterns of these three years were quite different. The first, with an annual total of 55 inches, was 11 inches above average; the second, with an annual total of 35 inches, was 9 inches below average (the driest year ever recorded at Samaru); and the third with an annual total of 42 inches was near average, though badly distributed. Despite these differences, the yield has been maintained at a level which compares favourably with crops produced under rain-grown conditions anywhere in Africa, and there has been no large seasonal variation. Also of considerable interest is the fact that all three crops have been ready for harvest early, and picking has been completed before the end of the year,

whereas on other cotton plots, often yielding very much less, picking had to continue two to three months later.[1]

Conclusion

The total annual rainfall is adequate to grow good crops of cotton, but the soils are such that they 'cap' easily and a large proportion of the rainfall may be lost by surface run-off unless measures are taken to prevent it. Under conditions where run-off is allowed to occur, shortage of moisture may be the factor limiting yield.

TABLE 11. *Treatments applied to the 'Well-treated' Plot of Cotton during Three Years, and Yields Obtained*

Details	*Year*		
	1957	*1958*	*1959*
Date of first cultivation	10 April	6 May	20 May
Manure (per acre)	3 tons night-soil compost	3 tons farmyard manure	2 tons night-soil compost
Date of ridging up	30 May	4 June	25 May
Date of cross-tying	13 June	5 June	9 June, following vertical mulching
Planting date	25 June	25 June	29 June
Seed used	Variety 26J. Acid-treated and agrosan-dressed	As for 1957	As for 1957
Fertilizer (per acre) applied by placement at time of planting	151 lb. mono-ammonium phosphate	194 lb. single superphosphate 140 lb. amm. sulphate	165 lb. single superphosphate 137 lb. amm. sulphate
Mulch	Dead grass	Groundnut shell	Groundnut shell
Date and method of application of mulch	14 Sept., in furrow	26 Aug., in furrow	5 June, 'vertically mulched' (see text)
Fertilizer (per acre) applied by placement 6 weeks after planting	112 lb. urea	None	None
Times sprayed with DDT/BHC insecticide	3	8	10
Post-planting rainfall ins.	37·9	23·2	28·4
Yield of seed cotton (lb. per acre)	1,930	2,246	2,206

It has been shown that the soil surface may be prevented from 'capping' by surface treatments; infiltration is thereby improved and run-off reduced.

Maximum retention of rainfall is ensured by the technique of cross-tying the ridges; but this used alone may lead to reduced yields in seasons of heavy rainfall through the bad effects of standing water between the

[1] Since the above was written a further crop has been harvested from this same plot; with similar treatment in 1960 a yield of 2,540 lb. per acre was obtained.

cross-ties. The best results are obtained where both cross-tying and a measure to improve infiltration, and consequently aeration, are used.

If cross-tying is to be the only measure practised, then the tying of alternate ridges may be a practicable interim measure avoiding the bad effects until methods of improving infiltration can be devised for general use by the native cultivator. Holding all the rainfall has never been shown to be disadvantageous at Samaru provided infiltration is good. Moreover, if all rainfall were held where it fell the need for expensive soil-conservation schemes would be obviated.

By conserving rainfall, improving the infiltration and aeration, very large increases in seed-cotton yields have been obtained. In three successive years of markedly different rainfall patterns a seed-cotton yield of approximately 2,000 lb. per acre has been produced on a plot which received every proved beneficial treatment including methods to conserve rainfall and improve infiltration and aeration. As yields of this level have not been produced previously, even where manure, fertilizers, or insecticides have been applied, it is concluded that lack of moisture and bad aeration have in the past set a 'ceiling' to seed-cotton yields.

With the removal of these limiting factors, other treatments are able to realize their potential.

Similar work is necessary to investigate whether these factors are equally important for the two other main crops, sorghum and groundnuts.

Acknowledgement. The author is greatly indebted to Mr. H. E. King, Officer-in-Charge, Empire Cotton Growing Corporation in Nigeria, for his continuous guidance and encouragement during this work and in the preparation of the manuscript.

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(*Received 3 September 1960*)

NOTE ON THE ESTABLISHMENT OF A LEGUME IN RANGELAND IN NORTHERN NIGERIA

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WITH PLATE 12

Summary

Simple methods of establishing *Stylosanthes guyanenis* ssp. *guyanenis* ('stylo') and *Alysicarpus glumaceous* (Vahl. DC) (alyce clover), which would be economically feasible for application to the extensive rangeland areas of Northern Nigeria, are described. Encouraging establishment results were obtained, both by sowing the seed in the most rudimentary of seed beds and by feeding stylo seed to animals grazing over the rangeland.

In Northern Nigeria, where the majority of the cattle are owned by the migratory Fulani people, the improvement of the extensive rangeland areas in the Northern Guinea Savannah and Sudan zones on which these cattle graze is of great importance. A series of investigations, most of which are necessarily long term, into the effects of management practices upon the composition and productivity of rangeland are in progress. One of the methods by which it is proposed to improve rangeland is by the establishment of a grazing legume in the sward. It has been recognized that there are economic limitations on the techniques suitable for the improvement of these extensive areas. Within these limitations only the most inexpensive methods of sowing the legume can be expected to prove worth while.

Experiments and Results

The most suitable legumes for use in this way are, in the Northern Guinea Savannah zone, *Stylosanthes guyanensis* ssp. *guyanensis* [1] commonly known as 'stylo', Brazilian lucerne, or *Stylosanthes gracilis*; and, in the Sudan zone where the dry season is too severe for stylo, *Alysicarpus glumaceous* (Vahl.) DC, an indigenous annual species commonly known as 'alyce' clover.

In 1958 a factorial experiment, F2(58), was started at Shika (lat. 11° 15′ N., long. 7° 32′ E.), in which these two legumes were sown in rangeland either in 6-in.-wide strips cultivated by hand hoe, or in grooves scratched on the ground with a pointed stick; and with or without superphosphate at the rate of 56 lb. per acre placed on the surface along the rows where the legumes had been sown. Other plots were broadcast with seed without any cultivation but with the addition of superphosphate broadcast at the rate of 112 lb. per acre. In 1959 these sowings were repeated on rangeland which had been protected from defoliation during the previous dry season and which had been burnt shortly before sowing. Counts have been made periodically of the number of sown plants found

[Empire Journ. of Exper. Agric., Vol. 29, No. 116, 1961.]

in sample lengths of row or in sample areas. A summary of these counts is shown in Table 1.

During the dry season 1959–60, the part of the experiment sown in 1958 was protected from defoliation and on 9 April 1960, after the first inch of rain of the year had fallen, this area was burnt. The fire killed out all the surviving stylo plants.

TABLE 1. *Average Number of Sown Plants per Yard of Row or, in the case of Broadcast Plots, per Square Yard*

(*To the nearest whole number*)

Treatment	*Sampling date*				
Sown 3 June 1958	*18 Aug. 1958*	*21 Oct. 1958*	*23 Feb. 1959*	*9 Sept. 1959*	*8 Apr. 1960*
Stylo in rows					
In cultivated strips	8	6	4	2	1
In scratched grooves	8	9	3	1	2
With superphosphate	9	10	4	2	3
Without superphosphate	7	5	3	1	1
Stylo broadcast	2	3	2	1	2
Alyce clover in rows					
In cultivated strips	7	7	0	3	0
In scratched grooves	6	5	0	15	0
With superphosphate	4	3	0	5	0
Without superphosphate	9	9	0	13	0
Alyce clover broadcast	1	3	0	4	0
Sown 19 June 1959	*14 Aug. 1959*	*1 Oct. 1959*	*8 Apr. 1960*		
Stylo in rows					
In cultivated strips	9	7	5		
In scratched grooves	7	7	2		
With superphosphate	9	8	5		
Without superphosphate	7	5	2		
Stylo broadcast	1	2	2		
Alyce clover in rows					
In cultivated strips	16	10	0		
In scratched grooves	6	4	0		
With superphosphate	15	12	0		
Without superphosphate	7	3	0		
Alyce clover broadcast	3	5	0		

A further experiment, F9(59), was started in 1959 at Shika. It had been observed that stylo seeds were present in the dung of cattle which had been grazing on sown stylo pastures. These seed were shown by germination tests to be still viable, and this suggested another possible method for the establishment of stylo plants in rangeland. Throughout July 1959 two herds, each of three White Fulani bulls, in separate rangeland paddocks, D2 and R2, were each fed a mixture of 2 oz. of stylo seed in 1 lb. of ground sorghum meal every day. At the end of the month the cattle were removed from the paddocks. During August 1959 groups of up to ten young stylo plants were seen outlining the position of the dung pats which had themselves been partially removed by termites and dung

beetles. By October very few of the dung pats remained but in many cases their positions could be clearly seen by the ring of stylo plants (see Fig. 1, Plate 12). In May 1960 the positions of the plants which had survived the dry season were plotted (see Fig. 2). Paddock D2, in which only 194 plants or groups of plants were found, had been grazed during October 1959 and February 1960; while paddock R2, in which 424 stands were found, had been grazed in March 1960 only.

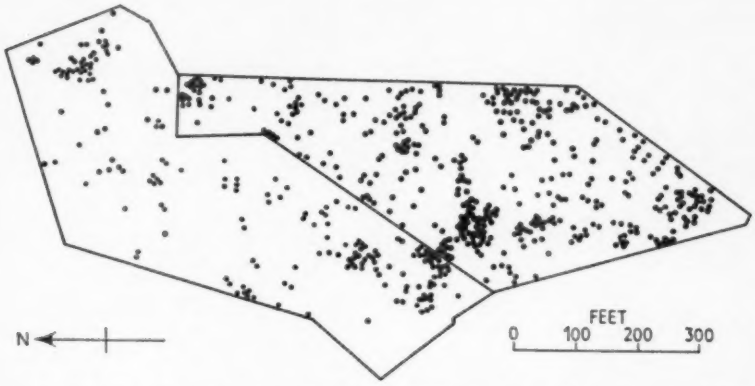

FIG. 2. Positions of stylo plants or groups of stylo plants in Paddocks R2 and D2 in May 1960. (R2 is the southernmost paddock.)

Discussion

These experiments have shown that it is possible to establish stylo and alyce clover in rangeland by fairly simple operations. In the case of the experiment described first, F2(58), plant counts were too variable to allow any significant differences between treatments to be determined, and indeed a satisfactory establishment was obtained even by the simplest method: sowing in a scratched groove without superphosphate and without previous burning.

Other rangeland grazing studies (A. B. Rains, unpublished data) have shown that the only time at which it is permissible to burn savannah rangeland is after the first inch of rain in the year has fallen. However, burning at this time in 1960 killed out all the stylo plants. Thus to maintain stylo in rangeland it is necessary to exclude fire. Alyce clover, being an annual, evades the fire challenge.

The second experiment demonstrates a simple and effective method of establishing stylo in rangeland. For wide distribution of the seed by this method, efficient herding of the cattle is required. There is a tendency for cattle to congregate and drop their dung in certain favoured areas. The effects of this tendency can be seen in the clumping of stylo stands in Fig. 2.

The effects of management in the first year upon the survival of the established stylo plants is demonstrated by the difference in stylo plant

populations between the two paddocks in May 1960. Other observation work has shown the slow growth of stylo in its first year. Preferably the young plants should not be grazed before the end of the first dry season.

Acknowledgements. The author is grateful to the Ministry of Agriculture for permission to publish this work and to Messrs. J. D. Scott, E. N. Ayinor, and L. E. Iduma for assistance in the experiments. Mr. A. J. Bennett took the photograph.

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(*Received* 10 *August* 1960)

FIG. 1. A typical group of stylo plants photographed on 4 November 1959. The dung pat has been removed by insects. The ruler measures 12 in.

THE YIELDS OF EIGHT VARIETIES OF SAINFOIN CUT AT DIFFERENT GROWTH STAGES

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Summary

Data are presented on the growth characteristics and green- and dry-matter yields of eight varieties of sainfoin cut at the pre-flower-bud stage, the pink-bud stage, and at full flowering.

Over the three-year period of the experiment, marked differences are seen between the Giant and Common sainfoins, and the selective factor separating these types is discussed.

SAINFOIN (*Onobrychis viciifolia* Scop = *O. sativa* Lam.) is a valuable forage legume because of its high protein content. It originated in central and southern Europe and temperate Asia and is best suited to soils containing a considerable amount of lime, but can be grown on clays and loams in relatively dry and warm climates. In the Swiss region of Jura sainfoin is an important pioneer crop on stony soils, and has shown promise as a pasture/hay legume in dry locations of South Africa, South America, and the United States [1]. In persistency Common sainfoin is superior to red clover, and in its ability to withstand hard grazing by sheep it is superior to lucerne. It is not adapted to a very wide range of soil conditions and therefore its general use is limited. Two types of sainfoin have arisen as a result of agricultural practice, namely, Giant sainfoin (*O. sativa* var. *bifera* Hort.) and Common sainfoin (*O. sativa* var. *communis* Ahlefeld). Giant sainfoin grows quickly and flowers early in the seeding year. It recovers well after cutting in the first harvest year and flowers again in the aftermath, which can be cut for hay. The Giant forms are short-lived and the yield declines considerably after the second year. Common sainfoin is slower-growing and the aftermath remains leafy with very little tendency to flower; this type yields good crops for a number of years.

Material and Methods

The present experiment was designed to provide information on the merits and characteristics of existing British varieties before embarking on a breeding programme. Data were collected on leafiness, persistency, winter greenness, and green and dry matter yields after cutting three times.

[Empire Journ. of Exper. Agric., Vol. 29, No. 116, 1961.]

Eight varieties were used, five Common and three Giant types:

Common sainfoins	*Giant sainfoins*
Vale of Glamorgan	English I
English Common	English II
Hampshire	Woodford
Eastern Counties	
Cotswold	

The trial was established at the Welsh Plant Breeding Station farm, Frongoch, on a very stony soil, 400 ft. above sea-level. The following fertilizers (cwt./acre) were applied to all plots during the trial:

	Super-phosphate	*Muriate of potash*	*Ground limestone*
	cwt./acre		
Seeding year .	4	2	40
1st harvest year	4	2	..
2nd ,, ,,	4	2	..
3rd ,, ,,	4	2	..

The experimental design was a randomized block with four replicates. Each main plot consisted of three drills of one variety, 12 ft. long and 2 ft. apart. Each sub-plot was one row and had a random cutting treatment. The sainfoin was inoculated and sown at the rate of 28 lb./acre milled seed. Before each cut the ends of the rows were discarded, leaving 10·5 ft. to be harvested. For the first harvest year the results are based on green weight, but subsequently dry weights were also obtained, 400-gm. samples of fresh material being taken for this purpose and oven-dried at 95° C. All varieties were cut three times during the first two harvest years but only twice in the third. The single-row sub-plots were cut at different stages of growth as follows: pre-flower-bud stage (A); pink-bud stage (B); and full flowering (C). There was an interval of 2 to 3 weeks between the three stages of growth A, B, and C, and about 6 weeks before the subsequent cuts of each treatment. The dates of cutting were:

	A *Pre-flower bud*			B *Pink flower bud*			C *Full flowering*		
Cut	*1953*	*1954*	*1955*	*1953*	*1954*	*1955*	*1953*	*1954*	*1955*
1	20/5	27/5	25/5	8/6	11/6	8/6	23/6	19/6	21/6
2	1/7	13/7G 13/7C	13/7	23/7	30/7G 5/8C	26/7	12/8	11/8G 25/8C	3/8
3	6/10	8/9G 14/9C	..	6/10	14/9G 22/9C	..	6/10	30/9G 22/10C	..

G = Giant. C = Common.

In the first harvest year both the Giant and Common sainfoins were cut on the same date. In the second harvest year, however, the differences in growth stage on any particular date were so marked that the

second and third cuts were made on different dates. The Giant sainfoins recovered earlier and in consequence were cut before the slower-recovering Common sainfoins. By the third harvest year the Giant sainfoins had thinned out so much that cutting on one date was again adopted.

Experimental Results

Total Yield

The yields of green matter in the first harvest year and of green and dry matter in the following two years are shown in Table 1. In the first

TABLE 1. *Total Yield of Sainfoin Varieties (100 lb./acre)*

Variety	*Green weight*				*Dry weight*	
	1953	*1954*	*1955*[a]	*Mean*	*1954*	*1955*[a]
Common						
Vale of Glamorgan	345	385	154	295	82	29
Cotswold	353	348	94	265	74	19
Hampshire	342	351	86	259	77	16
English Common	403	217	33	217	47	7
Eastern Counties Common	385	220	36	214	48	7
Giant						
English I	367	270	57	230	58	12
English II	260	186	17	154	40	4
Woodford	226	162	23	137	36	5
Mean	335	267	63	221	58	12
L.S.D.*	94	77	20	36	17	5

* Least significant difference at $P = 0{\cdot}05$ level.
L.S.D. for year green weight totals = 703.
" " interaction varieties × years = 137.
[a] Two cuts only.

harvest year all the Common sainfoins and English Giant I gave high yields which were not significantly different. English Giant II and Woodford were decidedly inferior in yield. In the second year the Common sainfoins Vale of Glamorgan, Cotswold, and Hampshire were superior in both green- and dry-matter yields and this superiority was maintained in the third harvest year. By this time Vale of Glamorgan sainfoin had outyielded the other varieties. The yields of the Giant sainfoins had declined considerably because the varieties were not persistent and there was an obvious thinning out of the drills. In an analysis of variance for yield over the three years there was an interaction of varieties × years (S.D. = 137), showing that while some varieties were as good in the second year as they had been in the first, others were markedly inferior. This was particularly true of Vale of Glamorgan, Cotswold, and Hampshire which gave greater yields in the first and second years than some of the Giant sainfoins had given at any time.

There was no significant difference in the year totals in the first two

years (S.D. = 703), but these were appreciably greater than the total in the third year where there had been only sufficient growth to take two cuts. The eight varieties can be divided into three yield groups:

(i) *High*: Vale of Glamorgan, Cotswold, Hampshire.
(ii) *Poor*: English Giant II and Woodford.
(iii) *Intermediate*: English Common, Eastern Counties Common, English Giant I.

Yield when Cut at Different Growth Stages (*Table* 2)

TABLE 2. *Percentage Contribution to Total Yield of Cuts made at Each Growth Stage*

Stage	*1953*	*1954*	*1955*	*Weighted percentage*
	per cent.			
A	30	25	21	27·0
B	37	38	31	36·8
C	33	37	48	36·2

The cuts at stages B and C were significantly superior to those taken at stage A. There was a year × growth-stage interaction showing that cutting was not best at the same stage in all years. In the first harvest year, cutting at stage B gave a significantly greater yield than cutting at A and C which did not give significantly different yields. In the second harvest year, cutting at A gave significantly inferior yield, while in the third harvest year, cutting at full flowering (C) gave the highest yield. The overall picture for the three years suggests that highest yields are given by cutting at B in the first year, B or C in the second year, and C in the third year. There was no interaction of variety × growth-stage, which shows that all varieties responded similarly.

Yield per Cut

The percentage contribution of each cut to annual yield in the first two harvest years is given in Table 3.

TABLE 3. *Percentage Contribution of Each Cut to Annual Yield in the First Two Years*

Cut	*1953*	*1954*	*Mean percentage*
	per cent.		
1	56	62	59
2	16	22	19
3	28	16	22

In an analysis of variance for the two harvest years there was a highly significant variance ratio for cuts, and for the interaction cuts × years, but not for the interaction cuts × varieties. The yield obtained from the

first cut was significantly superior to that of the other two being more than half the total production of the first and second years. The third cut in the first year gave a significantly higher yield than did the second, although there was no significant difference between the second and third cuts in the second harvest year. In the third harvest year, only two cuts were possible because there was insufficient growth for a third.

Percentage of Leaf

The dried samples from the five cuts in the second and third harvest years were separated into leaf and stem. The leaf included leaflets and petioles, while flower heads were included with stems. The mean percentage figures are given in Table 4.

TABLE 4. *Mean Percentage of Leaf from Five Cuts in Two Harvest Years*

Variety	*1954*	*1955*	*Mean percentage*
	per cent.		
Common			
Vale of Glamorgan	59	55	57
Cotswold	60	56	58
Hampshire	58	56	57
English Common	58	50	54
Eastern Counties	61	50	55
Giant			
English I	54	49	51
English II	56	50	53
Woodford	54	48	51

L.S.D. (cols.) = 6. L.S.D. (rows) = 5.

The Common sainfoins gave a higher percentage of leaf in both years, also English Giant II, which was not significantly inferior to the Common sainfoins in leafiness. The data also show that the varieties were consistently less leafy in the third year than they were in the second year, which may be due to age of stand or seasonal effects. The Common sainfoins showed less tendency to reduction in leafiness than did the other varieties.

Growth Characters

Observations were made on establishment, earliness of flowering, recovery after cutting, and winter greenness. A scale of marks 1–9 was used, 1 = the best in all the observations recorded and 9 = the poorest. Table 5 summarizes some of these results.

In the seeding year sainfoin was slow to establish and the plots became very weedy; this was particularly true of English Giant II and Woodford. English Giant I, however, was relatively quick to get away, and throughout was markedly superior to English Giant II and Woodford. In the first harvest year English Giant I, together with the intermediate-type varieties, was superior in bulk. The Common sainfoins were inferior in yielding ability until the spring of the second and third harvest years,

TABLE 5. *Establishment, Recovery after Cutting, and Winter Greenness Marks during the Three Years*

Variety	*Establishment* 2.12.52	*Spring growth* 1953	1954	1955	*Recovery after cutting on* 1.7.53	12.7.54	7.9.54	*Winter greenness* 1955
Common								
Vale of Glamorgan	5	5	2	3	5	5	3	4
Cotswold . .	5	5	4	6	6	5	4	5
Hampshire . .	5	4	4	6	5	5	4	5
English . .	4	3	5	8	6	7	5	8
Eastern Counties .	4	3	5	8	7	6	6	7
Giant								
English I . .	4	2	5	7	2	4	3	7
English II . .	7	6	7	9	3	7	7	9
Woodford . .	7	6	7	9	5	8	7	9

L.S.D. = 1.

when they came into their own; the Vale of Glamorgan was the bulkiest, and most uniform in growth. The Giant sainfoins, English I and Woodford, showed very sparse spring growth. Recovery growth was recorded about 4 to 6 weeks after cutting (Table 5). The English Giant I recovered most quickly, followed by the Common sainfoins which were much slower.

The winter greenness of sainfoin might well be one of its most valuable attributes, and this aspect was particularly noted during the trial. The Common sainfoins, notably Vale of Glamorgan, showed considerable greenness throughout the winter whereas the Giant sainfoins became brown.

The eight varieties fall into three morphological groups, namely: (i) the Giant sainfoins, English I, English II, and Woodford, which are characterized by tall, lax plants; (ii) the Common sainfoins, Vale of Glamorgan, Cotswold, and Hampshire, have low-growing leafy plants which give a dense stand; and (iii) Eastern Counties and English Common, which are intermediate. The Giant sainfoins flowered earlier than the Common varieties and they also tended to flower in the aftermath. The flowering dates recorded for all types showed a range in flowering from 7 to 19 May in 1953, and from 18 to 28 May in 1954. This difference in time of flowering was due to the lateness of the 1954 season.

Discussion

This trial was conducted over three years and the data show marked differences between Giant and Common sainfoins. Giant sainfoins are short-lived, giving a fair yield in the first year but lack of persistency thinned out the drills in succeeding years. In agricultural practice Giant sainfoin is usually sown as a one- or two-year hay crop on light soils where it can replace red clover. In this experiment English Giant I was far superior to English Giant II and Woodford; it was more vigorous, and had a higher proportion of persistent plants.

The Common sainfoins seemed to subdivide into what may be termed

the true Commons and those which were intermediate. The intermediate are those which originated in the eastern counties of England where it is the practice to take seed from a ley in its early years. Plants grown from such seed tend to be largely non-persistent and show some second flowering in the aftermath. The true Common sainfoins include Hampshire, Cotswold, and Vale of Glamorgan varieties in which localities the practice is to harvest seed from a ley in its later years, thus giving rise to plants which are longer-lived and which show little tendency to second flowering. Rees [2] showed that there was strong evidence of a correlation between longevity and once-flowering. This suggests that the original selective factor separating Giant and Common varieties was the time at which seed was harvested.

The growth stage at which the Common and Giant sainfoins should be cut to give maximum yield and highest percentage of leaf would appear to be the pink-bud stage (B). Fagan and Rees [3] found that leaf is much higher in nutritive value than stem, and therefore the proportion of leaf to stem in sainfoin hay has a considerable influence on its nutritive value; and that cutting at a mature stage of growth, e.g. full flowering (C), gives higher yields but inferior quality because of a decrease in protein content and an increase in fibre.

It is appropriate to consider the extent to which sainfoin is grown in the United Kingdom. Compared with lucerne, the acreage of sainfoin grown for fodder and seed production is small. Over the last seven years there has been a steady reduction in the sainfoin grown for seed, from about 3,000 acres in 1953 to less than 1,000 acres in 1959. Lucerne has largely replaced sainfoin because it is better-adapted to a wide range of conditions while sainfoin is limited to the chalk and limestone areas. If eelworm and Verticillium wilt become a menace to the growing of lucerne in this country, sainfoin may well become important again.

Acknowledgements. The author wishes to thank Professor E. T. Jones, former Director of the Welsh Plant Breeding Station, and Professor P. T. Thomas, present Director, for facilities to carry out this work. It is a pleasure to record thanks to Mr. W. Ellis Davies for his advice during the course of the work and to Miss Irene D. Rees for editing the typescript.

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(*Received 15 August 1960*)

THE VALUE OF FARMYARD MANURE IN MAINTAINING FERTILITY IN NORTHERN NIGERIA

E. B. DENNISON[1]

Summary

The results of experiments on the use of farmyard manure on the principal crops grown in Northern Nigeria, extending over a period of more than twenty years, are reviewed and discussed, with special reference to the relative responses of different crops, for which recommended rates of application are given.

It is accepted in both the temperate and tropical regions, especially West Africa [1, 2], that farmyard manure is generally beneficial to plant growth. At various times it has been put forward that organic manures are superior to inorganic fertilizers, and some extremists have suggested that the latter are harmful, although this is not borne out by experiments in temperate regions [3]. It has been reported that some workers even consider that insecticides, seed dressings, and the like are not necessary if farmyard manure is used. It is undoubtedly wrong to set up arbitrary barriers between organic and inorganic fertilizers [4], as the plant is capable of turning minerals into living matter. The full possibilities of 'humus' appear only when it is used in combination with suitable inorganic fertilizers [5] in a well-thought-out plan to increase fertility.

Experimental evidence is indecisive whether farmyard manure or the equivalent amount of inorganic fertilizers give the highest yield [2, 3, 6] but in the tropics it would appear that farmyard manure may have a greater effect than can be explained by its content of nitrogen, phosphorus, and potassium. This may be due to the fact that farmyard manure not only contains nitrogen but also encourages fixation of atmospheric nitrogen [7]. Long-term applications of farmyard manure in continuous cropping certainly seem to have a greater effect on soil fertility than inorganic fertilizers [8]. This is realized even by the local peasants; for example, around Kano City the farmers transport relatively large quantities of dung to their fields for considerable distances [9] even though inorganic fertilizers are readily obtainable and are sometimes used in conjunction with farmyard manure.

Much work was done in Northern Nigeria in the 1930's on the value of farmyard manure to various crops but recent work has been mostly on inorganic fertilizers. Nevertheless, a considerable amount of information has been accumulated on various aspects of manuring which it is worth while to review for two reasons. Firstly, it is surprising how little work has been written up on manuring in the tropics compared with the temperate regions. In Northern Nigeria, for example, it is generally agreed that farmyard manure is beneficial but the rates to be recommended are not always known even by advisory workers. Secondly, it is

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[Empire Journ. of Exper. Agric., Vol. 29, No. 116, 1961.]

of interest to see how far the work has progressed, so that duplication will not occur, and to provide a sound basis for future lines of work.

Before discussing rates of application some general points should be considered. For example, it is very important to know the optimum time for applying farmyard manure. It is always better to apply it to the crop, rather than during a preceding year, or on a grass ley; in the Sudan much of the value of the manure was lost through the local practice of applying organic matter to land that was about to go down to fallow [10]. Although farmyard manure decomposes slowly [11] leaching of nitrogen to the deeper soil layers soon takes place when the heavy rains start [12]. Thus it is best to apply farmyard manure at planting time, when rains are mainly light, which will allow it time to act. Heavy leaching is the reason why deeper-rooted crops, such as cotton, may show more response to the residual effects of farmyard manure than plants with surface roots [13].

Another aspect to be considered is which type of dung gives the best results. The dungs of different domestic animals vary; moreover, the type of food the animal receives affects the quantity of nutrients that its dung contains. Night soil, goat manure, and vegetable compost do not seem to be so effective as cattle manure in Northern Nigeria, but there is some indication that well-made night-soil compost has a longer residual effect. Groundnut cake has also been applied to a crop of groundnuts but the immediate effect was to depress plant growth severely.

With regard to pre-treatment of farmyard manure, some trials have been made with dung fortified with superphosphate. The results are not clear-cut, but on the whole it does not seem a worth-while practice. Furthermore, there seems to be little benefit from composting the manure, as compared with using it straight from the pens; in any case the labour involved definitely makes it uneconomic.

The ability of farmyard manure to maintain fertility in continuous cropping has received attention. A number of trials have been laid down, which show that continuous monocropping with certain crops is possible if adequate farmyard manure is supplied (Table 1). It has also been shown, in the Southern Guinea zone, that the usual three-year fallow, following the cropping cycle, is not necessary if farmyard manure is supplied at 2 tons per acre; with 3 tons per acre there was a gradual build-up of fertility [8]. As can be seen from Figs. 1 and 2, the ability of a 3-ton per acre application of farmyard manure to maintain fertility varied with different crops. Such a dressing maintained the fertility with millet (Fig. 1) and also fairly well with guineacorn (Fig. 2) but there was a definite decline of yield with groundnuts (Fig. 3). As shown later, groundnuts do not react so strikingly to manure as the two grain crops, and it might reasonably be concluded that only crops that respond well to dung applications can safely be grown continuously with the aid of farmyard manure.

The relative value of farmyard manure on different crops is often not taken into account on the grounds that organic manures are equally beneficial to all plants. Sreenivasan [13] states that experience has shown that it is better to apply manure to build up the general fertility rather

TABLE 1. *A Permanent Manurial Experiment on Guineacorn, Millet, and Groundnuts in the Northern Sudan Zone of Northern Nigeria*

Total yields (lb. per acre) from five plots of manured (3 tons FYM per acre), and five plots of unmanured land, using the Faulkner strip layout.

	Guineacorn		*Millet*		*Groundnuts*	
Year	*FYM*	*Nil*	*FYM*	*Nil*	*FYM*	*Nil*
1	962	709	987	937	1,004	964
2	266	153	1,034	790	1,209	1,027
3	1,384	670	1,282	1,093	1,008	925
4	1,196	575	1,114	820	1,267	843
5	1,182	321	779	477	1,037	774
6	1,216	372	789	493	1,241	873
7	1,153	531	890	507	966	632
8	368	169	697	384	725	522
9	1,178	316	649	359	1,020	752
10	612	80	709	291	1,056	724
11	420	26	468	156	942	745
12	1,024	161	232	107	589	415
13	1,307	75	880	386	657	525
14	674	190	667	437	987	608
15	780	20	688	337	1,087	526
16	555	27	876	495	881	326
17	740	76	727	479	595	426
18	1,154	135	691	359	488	238
19	889	87	1,053	544	395	177
20	..	..	1,355	560	503	276
21	..	..	873	374	798	520
22	..	..	732	198	475	365
23	..	..	752	207	776	478
24	..	..	786	252	915	461
25	..	..	715	444	825	460
26	..	..	1,163	447	525	313

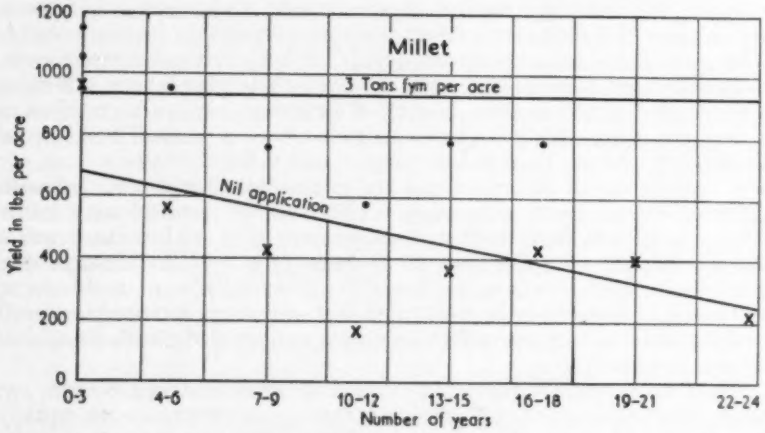

FIG. 1. Yields of millet grown continually on the same land for 24 years with and without farmyard manure (3 tons per acre).

than to determine the rates to apply to each crop. In Northern Nigeria it seems that certain crops respond better than others to organic manures as opposed to inorganic fertilizers, and in any case it is essential to have

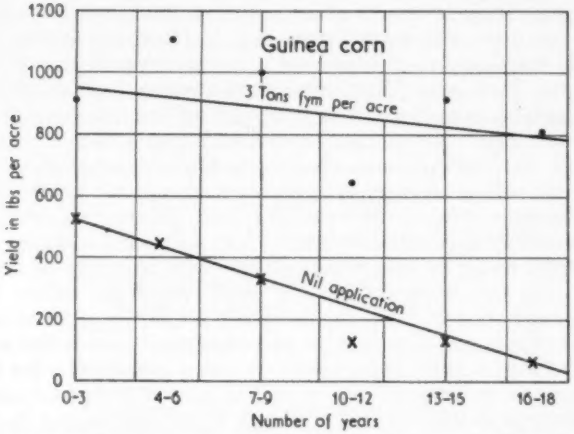

FIG. 2. Yields of Guineacorn grown continually on the same land for 18 years with and without farmyard manure (3 tons per acre).

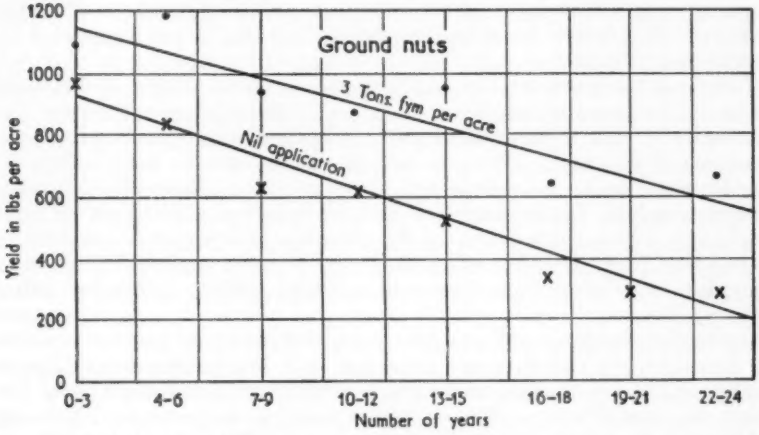

FIG. 3. Yields of groundnuts grown continually on the same land for 24 years with and without farmyard manure (3 tons per acre).

some guide as to when and at what rate to apply the limited amount of manure available.

Of all the major crops in Nigeria, guineacorn (*Sorghum vulgare*) seems to give the best response to farmyard manure, as is also found in other parts of the world [14]. It is advisable to apply any intended

dressing in this year of the rotation. As an average of four trials in the northern Sudan zone of Northern Nigeria, comparing dressings of nil, 1, 2, 3, and 4 tons of farmyard manure per acre, the yields of guineacorn were 846, 959, 1,117, 1,206, and 1,310 lb. per acre respectively. Three tons per acre seems to be an optimum dressing although as little as 1 ton may give significant increases [1]. However, it may be better to split the application up into equal portions for each year of the cropping. In the Zaria area (Northern Guinea zone) there is an indication that it is better to apply 1 ton in each year of the three-course rotation (cotton, guineacorn, groundnuts) rather than 3 tons in one year. On the other hand, in Makurdi area (Southern Guinea zone) it is generally accepted that where manure is available it should all be applied to the yams or the grain crop in the rotation (yams, guineacorn, benniseed).

Tubers usually give striking results with farmyard manure, although cassava seems to be an exception and to respond better to ammonium sulphate. On the other hand, for sweet potatoes, where farmyard manure is really worth applying, inorganic fertilizers seem to have relatively little effect, less than that on groundnuts or even millet or guineacorn. In a Latin Square experiment on sweet potatoes in the Southern Guinea zone, comparing nil, 1½, 3, and 4½ tons of farmyard manure per acre, the average yields were 7,155, 8,395, 8,405, and 10,390 lb. per acre. An average yield on peasant farms in this area would be about 7,000 lb. A dressing of 4 tons per acre is effective in the middle belt and farther north it is reported that even over 5 tons is worth applying. It was rumoured in Tiv country that the keeping quality of sweet potatoes was affected after heavy dressings of manure but this is not supported by experimental evidence.

Rice, groundnuts, and cotton respond to applications of farmyard manure, as found in other countries [15], but in Nigeria it seems that increases in yield with these crops are less than with guineacorn, yams, and sweet potatoes. With groundnuts yields increase with increasing applications up to approximately 2 tons per acre, above which further response is less. Superphosphate gives increased yields in most groundnut areas [16] and it is probably the phosphate therein that is the active ingredient [17]. It is therefore better to apply inorganic fertilizers to groundnuts, rather than farmyard manure, which is always rather scarce.

It has been suggested that up to 10 tons of farmyard manure per acre is beneficial on rice in some countries [18] but in Northern Nigeria inorganic fertilizers show more promise although insufficient work has been done on this crop. Sethi [19] has found in India that applications of farmyard manure affect the soil/water conditions, which has been substantiated in more temperate regions [11], and the water requirements of rice crops are lowered. This may be of value in places in Nigeria where the water supplies are short.

In America applications of from 6 to 9 tons of farmyard manure per acre are recommended by some authorities on cotton [20] but once again there is every indication that in Nigeria organic manure can be better utilized on other crops. As already explained, cotton can utilize

the residual effects better than most crops in the year following the application of farmyard manure [13, 15] but as cotton is usually grown in Nigeria as an opening crop after a fallow, this is of little practical interest.

Surprisingly enough there appears to be no special advantage in applying farmyard manure to some crops. Sugar cane, for example, does usually give some increase in yield, but as it is nearly always planted in Nigeria on live alluvial soil which is fairly rich in nutrients, there is little response. Barnes [21] states, 'the availability of artificials and the fact

TABLE 2. *Recommended Rates of Application of Farmyard Manure per acre in Northern Nigeria*

Crop	*Recommended rates of application*
Benniseed	Not economic to apply farmyard manure or inorganic fertilizers.
Cassava	If economic, best to apply inorganic fertilizers.
Cotton	2 tons, but best to apply to other crops.
Guineacorn	3 tons.
Groundnuts	2 tons, but inorganic fertilizers give better response.
Millet	2–3 tons.
Onions	3 tons.
Rice	If economic, best to apply inorganic fertilizers.
Sweet potatoes	4–5 tons.
Sunflower	If sufficient farmyard manure available: 2 tons on bad soil and 1 ton on good soil.
Sugar cane	Not economic to apply farmyard manure.
Tomatoes	3–4 tons.
Yams	3 tons.

that they do all and more than farmyard manure ever did has made them more attractive than manure'. Thus, as in the rest of the world [22], ammonium sulphate is the most favoured nitrogenous fertilizer for sugar cane where manuring is considered necessary.

Another crop that is not worth dressing with farmyard manure is benniseed, although in this case for quite a different reason. Benniseed will respond to adequate applications of manure [8] but the cash return is not enough to compensate for the labour involved, particularly when it can be better employed on another crop in the rotation. Inorganic fertilizers are also uneconomic. Sunflower gives a fairly low response to farmyard manure, and it is only worth applying 1 ton per acre on good soil, or 2 tons on poor soils, if there is sufficient to spare after the other crops have been treated.

It is impossible to give accurate figures for optimum applications for the whole country, but very fair estimates can be made, based upon the considerable number of trials and experiments carried out in the northern region of Nigeria during the last thirty years. A table of these recommended rates for each crop is given above.

Acknowledgements. The author would like to state that the work on which this paper is based was carried out over a number of years, and many members of the Ministry of Agriculture helped in the experiments. The author would particularly like to mention Mr. K. A. Watson and Mr. J. K. Obi, who analysed some of the results, and the

team of local personnel who carried out the long-term experiment on Kano Agricultural Station, the results of which are shown in Table 1. Messrs. Carter and Moczarski, Principal Agricultural Officers; Messrs. Offia and Awani, Assistant Agricultural Superintendents; and the library staff of the Regional Research Station, Samaru, also indirectly assisted in compiling this paper.

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(*Received 28 July 1960*)

A SIMPLE SYSTEM OF MANAGEMENT FOR SOIL AND WATER CONSERVATION AND DRAINAGE IN MECHANIZED CROP PRODUCTION IN THE TROPICS

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WITH PLATES 13–19

Summary

A system of tillage, based upon construction, by the plough, of broadlands (a modified form of the old English ridge and furrow), to control surface wash and improve drainage, has been subjected to critical trial under a wide range of representative conditions in several parts of Africa over the past decade.

The broadland is the nearest approach yet devised to a self-contained unit, the construction, maintenance, and cropping of which permit the farmer to participate fully in effective system for soil conservation and drainage.

With application over a wide range of conditions of climate, topography and soil, it provides, *inter alia*:

(*a*) yearlong protection controlling surface wash and improving drainage considerably; and

(*b*) a compact permanent workable unit suited to a wide range of cropping conditions, rain-fed or irrigated.

THE African tropics and hotter sub-tropics are witnessing a marked intensification of effort towards increased crop production. Projects both large and small, in which the keynote has often been the necessity for a mechanized approach for land clearing and crop production, have been launched, and although the machine has not yet increased productivity in the manner calculated, the seed of mechanization has taken root, and machinery will undoubtedly be used increasingly for crop production.

The traditional patchwork quilt of shifting cultivation is a system which, provided the fallow period is adequate, protects land and maintains fertility more effectively than any other system yet devised. But the machine will lead to more and larger cultivated blocks, and will cause increased soil loss, unless simple, inexpensive techniques of effective soil protection can be evolved.

Standard conservation practice does not adequately protect poorly drained erodible soils, often subjected to high-intensity rainfall, an increasing acreage of which will be cultivated. Moreover, in Africa, termitaria, usually with soil of high clay content, present another difficulty; they shed water rapidly, causing ponding, and they obstruct water disposal where land has been ridged to a gradient. This leads to breaches and thus no system can function in their presence.

The well-constructed contour bank is an effective safeguard against major erosion only; it does not prevent the occurrence of inter-terrace surface wash and gullying.

The grass strip provides less protection than the contour bank and tends to aggravate drainage problems.

Annual ridging can be dangerous, for even on 36 in. centres a ridge

[Empire Journ. of Exper. Agric., Vol. 29, No. 116, 1961.]

freshly thrown up is not sufficiently robust to withstand the high intensity of rainfall to which it is subjected so often in Africa.

Tying of ridges certainly keeps water in place, but is not suitable for all crops, and should a ridge overtop, the effect may be worse than if no protection were provided. Furthermore, the small crop ridge does not provide all-the-year-round protection, and thus a storm before ridging is done, or after harvest, could do severe damage.

The bench terrace, easily and cheaply built by reversible plough, provides adequate protection; but run-off must pass the length of the land to the outlet whether the crop is planted on the flat or on the ridge. Even when the terrace is well levelled longitudinally this passage impedes drainage of infiltered water. A plough furrow drawn the length of the step wall will assist drainage, but will be effective only if a terrace backslope is formed, and for this a reversible plough is necessary. Further weaknesses of the bench terrace are that the step wall cannot be cultivated mechanically and therefore is laborious and expensive to weed. Where 'one-way' implements are available, terraces must be cultivated in pairs; this practice is almost impossible to operate efficiently.

There is a tendency to accentuate the physical protection of soil and to neglect its drainage; indeed, attention is often focused so much on the need to conserve water that waterlogging results [1]. Conservation and drainage, therefore, must be approached *pari passu*, and a simple effective system must be devised to control them simultaneously under a wide range of conditions and without hindrance to crop production. The result must be soil held in position, absorptive, free-draining, and able to hold water from one wetting to another.

The Broadland System

The development of a system of 'broadland' cultivation on the basis of the old English ridge and furrow (see Figs. 1 and 2, Plate 13), has been studied by the author since 1949. This method, consisting of plough-made broadlands laid out on a specific gradient, controls run-off and drainage [2] under a wide range of conditions. Construction and maintenance can be undertaken by the farmer, under guidance in the first place, using standard simple agricultural equipment performing basic cultivations. Broadlands permit mechanized or other crop production without the burden of a complicated field layout (see Figs. 5, 6, 7, Plate 14).

The principal object of ploughing land in ridge and furrow in Europe was almost certainly the improvement of drainage on heavy clay soils. The system was made possible only by the introduction of the plough, which not only inverts soil, but also moves it horizontally, and ultimately vertically if ploughing is continued in one direction [3]. The broadlands thus formed produce two main effects:

(*a*) Run-off water is shed from crest to furrow during heavy rainfall (or following a sudden thaw of snow on frozen soil).

(*b*) Infiltrating water moves slowly through the surface soil towards the open plough furrow.

This second effect is less obvious than the first but is probably more

important. Under grass, infiltrating water moves outwards over the less permeable soil layer below the rooting zone. Under arable, a plough sole develops on the same contour as the surface but at cultivation depth, and thus infiltrating water will again move outwards over the plough sole. Thus, whether under grass or arable, the system is beneficial.

Design and Techniques of Broadlands Construction [1, 2]

The farmer installing broadlands needs help and co-operation from a soil-conservation engineer. Factors such as kind of soil; the duration, intensity, and frequency of rainfall; length of broadland; whether the prime need is for water conservation or drainage; and whether the land is to be used for rain-fed (non-irrigated) or irrigated crops or both, will determine the gradient.

For rain-fed conditions a constant-water-velocity channel should be adopted as a refinement, giving greater hydraulic efficiency; water flows at maximum permissible velocity throughout the length of the channel. This is achieved by a relatively steep gradient at the commencement of the furrow, becoming progressively less steep as the discharge of flood water increases along the length of the channel.

For irrigated (other than overhead) conditions a constant gradient is preferable, to ensure the same gradient for the crop at any point of the broadland. The gradient selected will be governed by all the factors mentioned above plus two important additional ones. First, the best grade for optimum water penetration is required. Secondly, where supplementary irrigation is practised, due account must be taken of the likelihood that rain may fall soon after an irrigation, resulting in high run-off.

Although it can be argued that falls of rain often follow one another, producing the same effect as a rain following irrigation, the gradient used for the latter condition introduces the complication of often leading to shorter broadlands, and the need for a more robust carefully built crop ridge.

As an example, at the University College Research Station, Nungua, on the Accra Plains, a highly erodible sandy soil requires drainage. The gradient selected by Mr. S. Smuts, Soil Conservation and Irrigation Engineer, was one commencing at 1:150 and gradually falling to 1:450. The broadlands in question are not irrigated and are about 1,000 ft. long. Rainfall intensity may rise to 3–4 in. per hour. Three falls of over 5 in. in less than 12 hours were experienced in 1959; the pattern of two of these falls is shown in Table 1.

The total rainfalls recorded for June 1955 and June 1959 were 21 and 19 in. respectively. After five years of continuous cropping, these broadlands withstood the above severe test well, and produced 2,000 lb. of maize per acre on a field scale.

Where blocks of land of an appreciable size are to be cultivated, the run-off and drainage water must be disposed of without interfering with crop production. A 40/50 HP tracklayer with dozer blade and 3–4 cu. yd. scraper is an economic unit for light scrub or tree felling, filling of holes created by uprooted trees, and planing off of small- to medium-sized

termitaria. Where removal of large termitaria (25 to 30 ft. in diameter and over 6 ft. in height) is too costly, cultivation of blocks exceeding 1 acre for annual crops may cause erosion and waterlogging. (Obviously for medium to large trees a more powerful tractor, or a different land-clearing system, would be required.)

The key gradient is next pegged and demarcated, straightening-out being kept to the minimum. Marking is best done by a single cultivator tine, the mark representing the crest of the broadland.

Lines parallel with this 'key-line' are demarcated on either side, by pegging and marking, or by marking direct with one man walking on the 'key-line' holding a wire or cord the other end of which is attached to the

TABLE 1. *Patterns of two Torrential Rainstorms at Nungua in 1959*

Date	*Fall*	*Onset*	*Cessation*	*Duration*
2 June	1½ in.	22·30 hrs.	00·30 hrs.	2 hrs.
3 „	3 „	00·30 „	02·00 „	1½ „
3 „	2 „	02·00 „	06·00 „	4 „
Total	6½ in.			7½ hrs.
27 June	2 in.	10·30 hrs.	11·30 hrs.	1 hr.
„	1½ „	11·30 „	17·00 „	5½ hrs.
„	2 „	17·00 „	17·30 „	½ hr.
„	¼ „	17·30 „	18·30 „	1 „
Total	6¼ in.			8 hrs.

centre of the tractor. The driver must keep the cord just taut, which he soon learns to do. It is, of course, important that the cord be kept at right angles to the line, especially when rounding bends, to ensure a constant width. The pace should be set by the driver, whose attention will be fully engaged on watching the cord, the man walking the line varying his pace to suit. The gradient of each line demarcated should be checked and compared with that of the key, paralleling continuing until the gradient begins to deviate too much from the key, at which point a correction strip is inserted and a new batch of parallels are demarcated. (The permissible degree of gradient deviation varies with the gradient in use and in relation to the point where the deviation occurs. If, for example, a gradient to give a constant maximum permissible water velocity has been selected, erosion will occur if it is exceeded; on the other hand, if the gradient is reduced, disposal of water will be slower and may sometimes cause temporary crop flooding. The permissible deviation will also vary according to the soil, the kind of crop, depth of cultivation, and run-off; in short, it will be very much a question of trial and error under local conditions. In practice considerable deviation can be tolerated without too great a loss in efficiency.) The width of the broadland will depend upon slope, soil, local climatic conditions, crops to be grown, and implements to be used.

Once all the crest lines are demarcated it is advisable to mark the furrows, this being the easiest way to ensure that the completed broadland will be the correct width. Ploughing then commences with whatever

tractive force and plough are in traditional use (bullock, horse, or tractor; and mouldboard or disk) the first furrow always being turned uphill. The value of a reversible plough is immediately apparent, as no idle travel need occur if a plough be used for marking out (Fig. 3).

The number of ploughings required to form the broadlands depends on the soil, its condition, the type of plough used, and quality of work;

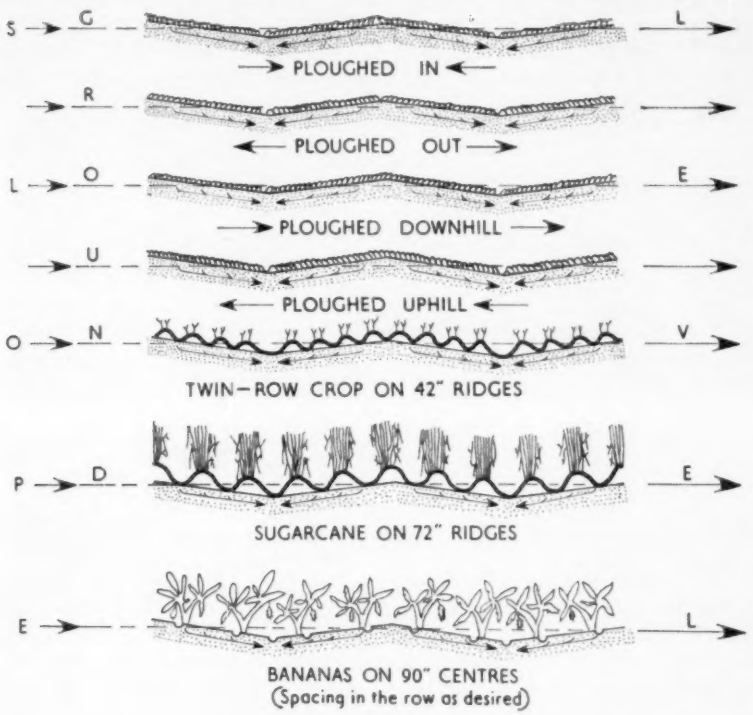


FIG. 3. Broadland 30 ft. wide

but two ploughings should be given initially. The height and shape of a broadland when first ploughed up is usually deceptive, as it will tend to settle considerably, the sides remaining concave upwards rather than convex (the shape they will assume, with ploughing, after a few years), Figs. 8 and 9, Plate 15. To ensure more positive movement of soil it should either be allowed to settle, or be consolidated between ploughings; a green-manure crop such as sunnhemp will facilitate this process. The beneficial effect of this particular treatment on land management will be increasingly apparent for several seasons, until the convex relief throughout the profile is achieved.

For satisfactory water disposal, the open plough furrow between the broadlands must be extended well into the main drainage line, as its

bottom is below ground level, and any slight obstruction in the furrow will impound water for a considerable distance, thus impeding drainage. The amount of land devoted to drainage furrows will be found to lie between 5 and 10 per cent. of the area under broadland cultivation, and will be determined by run-off, depth of soil, gradient in use, and crop-row arrangement.

As previously stated, the width of the broadland depends upon crops, implements, rainfall, &c., but two important points are determining factors. For crops requiring inter-row widths of about 36 in., four-row equipment is not easy to operate in a normal field layout. Much study

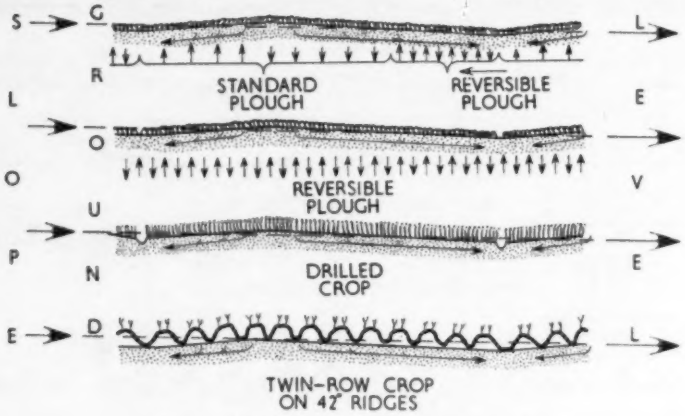
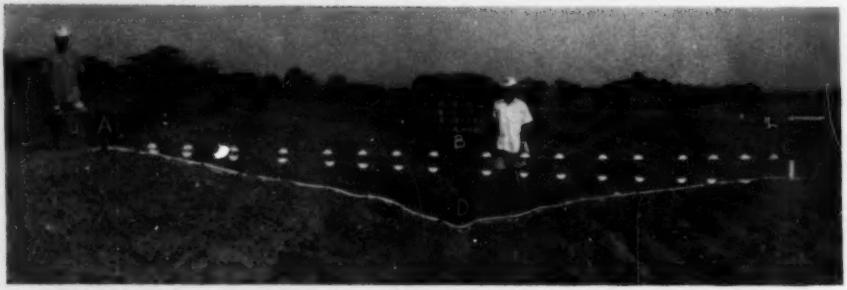


FIG. 4. Offset-crest broadland 46 ft. wide

remains to be done on inter-ridge width, but ridges on 42-in. centres certainly are very much more robust than those on 36-in. centres. If the former is selected, even three-row equipment will be found cumbersome, two-row being more within the capacity of the driver and better suited to average land conditions. Thus the broadland can be any multiple of 7 ft. to which must be added an allowance for the drainage furrow. Up to a basic width of 28 ft. (30 ft. total) and land slopes of 2 per cent., the crest should be formed in the middle of the broadland, but where a wider broadland is preferred or where slopes lie between 2 and 5 per cent., it is advisable to offset the crest: the lower side being, in multiples of 7 ft., twice the width of the upper (Fig. 4). This obviates the lower side becoming too steep, which increases rilling and causes side-slipping of implements, mounted and trailed. The crest generally must be raised sufficiently to cause water from the upper side of the broadland to be returned to the furrow above it. For construction and maintenance the offset broadland requires a reversible plough, otherwise much idle travel occurs. The need for a reversible polydisk, an implement yet to be produced is evident. Figs. 5, 6, 7, 8, 9 (Plates 14 and 15).

Although it is claimed that the broadland can be built by any plough

FIGS. 1 and 2. An example of Ridge and Furrow in Warwickshire—England.
Width of land. 28 ft.
VI crest furrow + 2 ft.
Note sedge in furrow.



FIGS. 5 and 6. This broadland has been cropped once a year for 5 years. Its width was selected to accommodate eight 3-ft. crop rows. Fig. 6 shows a complete broadland.

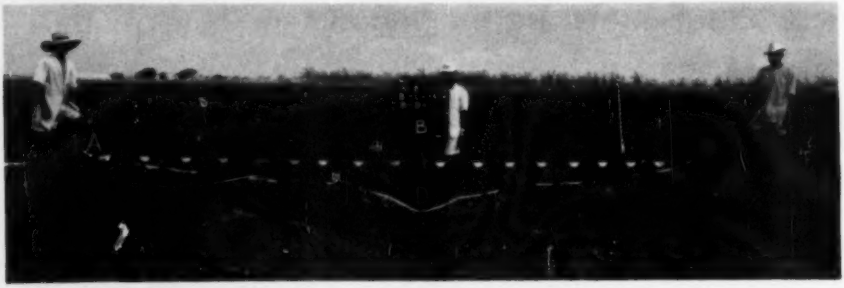


FIG. 7. Broadland on heavy black clay, on flat topography. (N.B. distance B–D is measured from wire to furrow shoulder.)

FIG. 8. FORMATIVE STAGE

This broadland has been twice ploughed. Note the concave relief between A–D. (This photograph was taken when soil was dry following ploughing. After rain the concave relief will be even more marked.) The small pool of water below D is seepage from an irrigation canal 50 yards up slope.

FIG. 9. MATURE STAGE

This broadland has been cropped once a year for five years. Note the slight convex relief between A–D. This broadland width was selected to accommodate twelve 3-ft. crop rows. N.B. A–D is the lower side of one broadland, A–D is the upper side of the broadland below it.

FIGS. 10 and 11. Easy inter-row cultivation of emerging maize on an offset-crest broadland. Here, row widths of 3 ft. were being used and two rows being cultivated at a time. This arrangement is being discarded where possible in favour of row widths of 42 in. carrying twin rows. Most row-crop tractor manufacturers provide wheel settings of up to 7 ft.

FIG. 12. A promising crop of maize, hand-planted by a peasant farmer in Southern Ghana on broadlands prepared for him

FIGS. 13 and 14. 9-in. twin-row staggered maize seeding, with velvet beans down the middle, on 42-in. centres; grown for silage.

FIG. 13. Applying a side-dressing of ammonium sulphate and hilling. FIG. 14. Harvesting. The crop yielded 13 tons/acre in 65 days.

FIG. 15. Drilling soya bean on a simple broadland on black clay soil with a 12-ft. combine drill. Note evenly dried surface soil well cracked.

FIG. 16. Rapid weeding of four 3-ft. ridges per run on an offset-crest broadland.

FIG. 17. A good stand of groundnuts hand-planted by a peasant farmer in Southern Ghana on broadlands prepared for him.

FIGS. 18 and 19. 6-in. twin-row groundnuts (Fig. 18) and soya beans (Fig. 19) machine-planted on 42-in. centres.

pulled by anything, it cannot be denied that tractor-mounted equipment is found most convenient in use and gives the best results.

Maintenance Techniques

Broadland shape is maintained primarily by the plough; broadlands can be ploughed in, out, all uphill or all downhill, but generally one ploughing up to the crest each season is necessary and will suffice. A single gang polydisk is extremely useful for initial shaping. It is also useful for maintaining shape, where it is necessary to do a shallow weeding in between ploughing and planting, and where it is desirable not to flatten the land, as occurs when an offset or disk harrow are used.

The drainage furrow between broadlands must be kept open; this can be achieved either by a well-finished plough furrow or, at little cost, either manually or by a single Lister bottom fitted with extensions to obviate shoulder effect. For perennial crops this furrow maintenance is of paramount importance because some soil does wash down and furrows become silted, thus raising the level of drainage. Without such maintenance, drainage efficiency is reduced. Depending on the crop spacing, a plough is used for rebuilding the whole shoulder, in which case a green manure crop could be turned in or the furrow is cleaned out by a Lister bottom.

One of the features of this system is its ability to conserve water on less heavy and freer-draining soils, for example by tying the drainage furrow. Should excessive run-off occur, the ties will be washed away without damage to the crop, only slight soil-loss occurring. However, this practice would not apply in the cultivation of heavy or difficult land liable to excess water from heavy rain and poor drainage.

As previously stated, the efficiency of this treatment improves progressively for several seasons, until the requisite shape throughout the profile is achieved. On shallow soils with clay subsoil a fertility gradient may be apparent for the first one or two years; but with cultivation and some soil drift down the slope of the land the soil profile will become increasingly homogeneous and this undesirable feature will disappear. Furthermore, during the transition from concave to convex relief, some waterlogging may well occur from time to time but this will gradually become less-and-less apparent.

Cropping on Broadlands

Emphasis is placed on the importance of devising a practice which maintains crop production over the widest possible range of conditions, at the same time demanding of the farmer the minimum amount of outlay and effort over and above what he does by tradition or of necessity.

The three major soils of the Accra Plains all occur on the University College of Ghana Agricultural Research Station at Nungua [4, 5]. They are:

Akuse Series

An intractable black montmorillonitic clay averaging 3 ft. in depth. In the dry season the clay shrinks considerably, producing a network of

deep cracks. In the rainy season the soil swells, closing the cracks and becoming plastic throughout the profile. Internal drainage is then very slow unless assisted artificially; run-off can be very high.

Simpa Series

A fine- to medium-grained sand or sandy loam, varying between 6 in. and 3 ft. in depth, overlying a 1–2 ft. layer of quartz gravel. This in turn overlies impermeable decomposing rock impregnated with illuvial clay. Drainage is slow through the sand, fairly rapid through the gravel, and negligible through the illuvial clay. Accordingly the soil is weakly drained, very erodible, and caps when dry.

Agataw Series

A fine sand to fine sandy loam 6 in. deep, overlying compact impermeable illuvial sandy clay. A grey planosolic soil of solonetzic character, very erodible and weakly drained.

TABLE 2. *Yields of Maize (lb./acre) on Agataw soil (planosolic)*

Treatment	*Acreage*	*Yield*
Bench terrace	6·5	1,035
Broadland	13·5	1,950

TABLE 3. *Yields of Cavendish Bananas (lb./acre) on Akuse soil (black clay) (Spacing 10 × 14 ft.)*

Treatment	*Yield*
Broadland	9,440
Ridge .	7,770
Flat .	5,420

Broadlands have been set out on all of these soils and have proved most satisfactory, especially when compared with other systems which have been tried, namely narrow-based terraces, bench terraces, and grass strips. Many advantages of broadlands have become apparent and are listed later. To substantiate these, however, Table 2 compares the yields of maize grown on broadlands and bench terraces on Agataw soil; and Table 3, the yields of Cavendish bananas grown on broadlands, ridges and flat planting on Akuse soil. In a small experiment on the black Akuse clay maize planted flat (no broadlands, no ridges) yielded only 500 lb. per acre, whereas yields of 3,000 lb. per acre on a field scale have been achieved with broadlands (4,000 lb. per acre in variety trials). Consistently high yields are being maintained on broadlands with other crops, as shown in Table 4.

Use of Broadlands for Various Crops. See Figs. 10, 11, 12, 13, 14, 15, 16, 17, 18, 19 (Plates 16, 17, 18, 19)

Depending on the crop, the 42-in. ridge accommodates either a complete or a staggered twin row and though row or ridge width varies

according to local conditions, there is less risk of overtopping with the 42-in. ridge than with the 36-in. ridge, the former being taller and more robust. Provided that adequate planing has been done prior to ploughing and that a gradient has been maintained, each ridge should carry and discharge its own run-off water. If, however, a ridge does overtop and causes the inevitable break through successive ridges, erosion is checked at the plough channel which has ample capacity for the entire broadland run-off. The choice of width of broadland depends on the crop, and on the equipment to be used for planting and harvesting. Where a range of

TABLE 4. *Yields of Other Crops on Broadlands*

Crop	*Yield per acre*	*Fertilizer lb./acre**	*Remarks*
Soya beans . .	900 to 1,100 lb.	100 T/S	Steady yield-increase over 3 years. Harvested by combine
Millet (*Pennisetum typhoidem*) and Velvet bean (*Stizolobium* sp.)	up to 15 tons	100 T/S, 150 A/S	Fodder for ensilage
Maize and Velvet bean	up to 15 tons	100 T/S, 150 A/S	Fodder for ensilage
Sugar cane . .	60–75 tons cane or 7–8 tons sugar	100 Superphosphate	Supplementary irrigation; black clay only
Tobacco . . .	900–1,100 lb. cured leaf	75 A/S, 200 T/S, 120 M/P	Supplementary irrigation; sandy soil. Medium-grade leaf

* T/S = 'triple' superphosphate; A/S = ammonium sulphate; M/P = muriate of potash.

crops is to be grown this aspect requires careful planning, although, from experience it is found that the broadland suits a surprisingly wide range of conditions with little inconvenience and land waste.

In general, it can be said that early planting gives higher yields. Firstly, therefore, as much field work as possible must be done before the onset of the rainy season; soil is dry and there is not the need for haste as there is when rain has fallen. It is assumed that the plough has followed soon after the previous season's crops.

Secondary Tillage and Application of Fertilizers before or at Sowing or Planting Time

For secondary tillage any of the standard types of equipment, tine or disk, can be used without difficulty, the disk being rather more positive because soil can be moved up or down the slope at will.

Where a basic application of fertilizer is necessary, deeper root development and better drought-resistance are usually promoted by its placement 4 to 6 in. deep, preferably by applying the fertilizer and doing secondary tillage as one operation. For this purpose, for crops grown on

the flat, a reversible polydisk fitted with a fertilizer box would be most useful. For ridge-grown crops a simple method for deep-placing of fertilizers is to apply the fertilizer in a band on the surface, and ridge up over the band. There is far less risk of undetected fertilizer spout blockage with this method because the driver can see the fertilizer dropping. A toolbar with two fertilizer cans mounted forward and with three ridging bodies to throw up two ridges over the fertilizer is a versatile implement which can be used not only for applying the basic fertilizer, and for ridging, but also for fast inter-row cultivation, side dressing and hilling.

The advantages of having land thus prepared by ridging are:

(1) As soon as a planting rain falls (usually not less than 1 inch suffices) planting can commence with the minimum of delay as the field is already marked out. This is of great benefit for hand planting. For tobacco and other transplanted crops, marking and forming of planting holes on the ridge ensures that, in the event of a marginal planting rain, all water possible is conserved and the soil is wetted below the base of the hole. But where machine planting is planned, pre-rains ridging is equally important as the ridges enable much faster planting to be achieved and, if rainfall has been heavy, an earlier start to be made. Provided planting equipment follows the ridging sequence, there is no difficulty about holding the planter on the ridge if the stabilizer bars are used.

(2) On the flat, weeds emerging together with the crop may well be difficult and more expensive to control. An extra preplanting cultivation for weed control may be impossible and valuable soil moisture may be lost, resulting in a patchy emergence. On ridges, however, plants stand proud and weed can be killed close to them when both are young without risk of covering. Inter-row cultivation is easy. Water loss is reduced to a minimum as no soil disturbance occurs; this results in better emergence.

Planting Annual Crops

Drilled or broadcast on the flat, e.g. sorghum, millet, soya, upland rice, *Urena lobata*, sunnhemp, wheat, barley, oats.

Row crops, mostly grown on ridges, e.g. maize, cassava, cotton, sunflower, yams, groundnuts, tobacco, beans, sorghum, castor, silage crops (maize and velvet beans), soya, millet, pyrethrum, vegetables.

To reduce capital outlay on equipment for planting and fertilizer application, hand planting of row crops such as maize, cotton, sunflower, tobacco, cassava, castor, and silage mixtures should always be considered where its cost is similar to that by machine, and seasonal labour is available.

Irrigation of Annual Crops

Flood irrigation cannot be satisfactorily applied to annual crops grown on broadlands, so that swamp rice is not a suitable crop. On the other hand, overhead irrigation is just as practicable for other crops grown on broadlands as it is with other systems of land management.

In all cases where irrigation is practised on broadlands, run-off water

is discharged longitudinally, and protection must be provided at the point of discharge into the drain. Infiltrating water, on the other hand, drifts laterally into the open plough furrow in the usual way. For sandy soils the 42-in. ridge will be found superior to the 36-in. ridge, primarily because it withstands rain better. There is always the risk of heavy rainfall following an irrigation and causing high run-off. Moreover, irrigation water erodes the side of the furrow, and therefore the 42-in. ridge requires less maintenance.

Rather more attention must be paid to ensuring that each ridge can carry its own water throughout its length without the risk of a break through, and this may necessitate once or twice levelling after ploughing up. Ridges will not, however, impede drainage, as although most of the run-off water is discharged longitudinally, continuous lateral drainage beneath the ridges may occur. Good drainage is the prerequisite for irrigation not only to obviate salt accumulation but also to ensure adequate soil aeration, thus permitting the crop to use as much of the water as possible.

Perennial Crops

For growth on broadlands, typical perennial crops are: sugar cane, sisal, tea, coffee, cocoa, bananas, citrus, oil palm, rubber, pineapple, Napier grass (*Pennisetum purpureum*). For such crops the width of the broadlands depends upon the spacing required.

For non-irrigated crops or those receiving overhead irrigation and requiring a spacing of 14 ft. or more, one row along the broadland crest is generally best and on this spacing the broadland is wide and robust enough to retain its shape for several years, at the same time preserving its drainage efficiency.

Where row spacing is less than 14 ft. it is advisable to retain a broadland width of at least 16 ft. in which case rows can straddle the crest.

For irrigated crops, much depends on the crop and the type of irrigation best suited to it. Water can be siphoned from a furrow drawn down the broadland crest to a basin formed around a plant or tree. This method is useful where water penetration is difficult, but where high run-off conditions occur, a relatively steep gradient is required to remove surplus water. Alternatively, basins can easily be built between the two rows of plants across the crest. Application of water, however, is then on a make-and-break basis whereas, with the former method, a permanent through furrow is preserved. Another method is to form furrows along the crest side of each row. There is, of course, no reason why any crop, whatever its row-width requirement, should not be planted on a ridge. In fact, for sugar cane this would be normal practice (J. M. L. Kowal and P. R. Hill—unpublished work). Once the ridge is formed irrigation becomes easy, and here again, gradient and rate of application can be varied to suit run-off and rate of penetration.

Advantages of the Broadlands System

1. Protection and drainage are achieved by a system of tillage, for which standard agricultural equipment is used, without hindrance to

crop production. Almost all crops, whether rain-fed or irrigated, can be accommodated.

2. Apart from major diversion banks for flood protection, no other physical works are required, as the broadland is a unit of protection in itself.

3. All-the-year-round protection is achieved. (A great weakness of the simple ridge is that, even if it were an efficient form of protection, it is not present throughout the year. Thus a rain out of season can often do irreparable damage before ridging commences or even after harvest.) Such natural soil movement as does occur is local only, i.e. to the furrow, where it is deposited and thereafter is returned to the broadland by cultivation.

4. The frequent interception of run-off water, together with correct depth of cultivation of well-drained aerated soil, ensures maximum water conservation and controlled disposal of the surplus.

5. The consequent improved drainage provides better conditions for crop growth and thus higher yields. There is no evidence to date that too much water is being removed whatever gradient is in use. On the contrary, standard practice, where impeded drainage or even water-logging frequently occurs, invariably produces earlier wilting and lower yields.

6. Ponding is eliminated.

7. Once formed, the broadland is a compact workable unit. The customary setting out of land to be ploughed following a crop harvest, is abolished; moreover, it is virtually impossible to make errors in cultivation.

8. More rapid surface drying after rainfall permits earlier and more effective cultural operations, and thus increased hours of work. Indeed, on heavy clay soils even when frequent light falls of 'topping-up' rain occur, it may mean the difference between being able to farm or not to farm (that is, to miss a season).

9. In addition to providing effective protection and/or drainage, the system is suitable for all soil types.

Acknowledgements. This investigation has extended over a period of years. The author has been fortunate in the assistance he has received from many people, much of which he cannot specifically acknowledge.

He is especially indebted to Professor A. H. Bunting, Professor of Agricultural Botany, Reading University (formerly Chief Scientific Officer to the Overseas Food Corporation), for early encouragement and continued interest. He is grateful to Mons. M. Rossin, Director General of French Research and Extension Overseas, and Mons. M. Guernier of the Compagnie Generale des Oleagineaux Tropicaux for making his extended visit to French West African Territories possible, and to them both and to Mons. Paul Coleno for their assistance and interest; to Mr. Jas C. Boyd who, by courtesy of Messrs. Massey Harris Ltd. invited the author to lecture and demonstrate at their annual tropical mechanized agricultural course for four years; and to the late Mr. R. I. Barker under whose stern but able tutelage the author learned something of the art of conservation and drainage of soil in Essex.

Finally the author wishes to thank Professor J. F. V. Phillips, Mr. S. J. Smuts, and Mr. G. G. Corbett for sustained valuable criticism throughout the work and for their helpful comments on the draft of the manuscript; Messrs. D. J. E. Nimako and A. A. Quarcoopome for their devotion and enthusiastic assistance in the field at all times; Mrs. J. Rose Innes for assistance with photography; and the University College of Ghana for facilities provided since 1954.

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(*Received 7 July 1960*)

AN ALTERNATIVE TO FLOOD IRRIGATION OF SUGAR CANE IN BRITISH GUIANA

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Summary

This paper describes an experiment designed to investigate the rate of water percolation through the raised beds on which the cane is grown, from infield drains filled with water. Twelve different mechanical methods of seed-bed preparation are described and the effects of these on the rate of percolation of water through the beds have been investigated. This was accomplished by observing the depth of water which had percolated into conveniently placed boreholes across the bed, after various lengths of time had elapsed after filling the drains with water.

The results show the undoubted value of deep ploughing combined with 2-way subsoiling in increasing the rate of water percolation through the bed. Utilizing this fact, an alternative method to complete-field flood irrigation in British Guiana sugar-cane cultivation is suggested, and an indication of the advantages of the system is given.

SUGAR CANE is the main agricultural crop grown in British Guiana, approximately 100,000 acres being devoted to its cultivation. Normal field acreage varies from 2 or 3 acres up to over 20 in certain areas, the average probably being about 12 acres. Due to a heavy but seasonal rainfall of from 60 to 100 inches annually, and the flat nature of the land, sugar cane is grown in rows planted across convex-shaped beds varying in width from 12 to 36 feet and running the length of the field. No overhead irrigation is practised, and dry-season irrigation is accomplished by flooding fields to a depth of a few inches over the bed tops. This method has three main disadvantages. First, it is wasteful of a water supply which is often limited, especially in a prolonged dry spell. Secondly, plant nutrients are leached from the soil and lost in the drainage water. Thirdly, the soil structure is often seriously damaged, especially on the heavy clay soils which make up a large part of the cane-growing area.

Apart from overhead irrigation, which is considered economically impracticable, an alternative to complete field flooding would be to fill the infield drains with water and allow this to percolate throughout the beds. This method has failed in the past owing to the impermeability of the soil in the beds. It is thought that the resistance to free water movement has been caused by soil compaction resulting from failure to use the correct soil-cultivation techniques, especially subsoiling and mole draining.

Experimental

Details of site

This work was done on a field which had had various cultivation treatments, as part of a large experiment designed to investigate the

[1] Previously with Booker's Sugar Estates, British Guiana.

[Empire Journ. of Exper. Agric., Vol. 29, No. 116, 1961].

effect of mechanical methods of seed-bed preparation on final yield of cane.

The previous ratoon crop had been cut and the remaining trash burnt off so that it did not hamper cultivation later. Complete flooding of the field for a period of 6 weeks had killed the old stumps, and on releasing the flood water the field dried out sufficiently for the heavy implements to begin work two weeks later. The seed-bed was prepared within 10 days, and cane was planted two weeks later. The work described in this paper, on rate of water percolation, was done when the cane was 8 weeks old.

Mechanical Cultivation Treatments

The field was divided along its length into beds about 37 ft. wide by drains approximately 2 ft. 6 in. deep and 3 ft. wide. The beds were convex and the drains had to be filled in before any subsoiling or other cross-cultivation could be done. The required convex form was then restored by redigging the drains, followed by cultivations along the beds.

The various methods of seed-bed preparation selected for this work on the rate of water percolation through the bed consisted of all combinations of the following:

Across-the-bed cultivations:

A. No subsoiling.
B. Once subsoiling.
C. Twice subsoiling.

Along-the-bed cultivations:

1. No subsoiling; deep mouldboard ploughing and harrowing.
2. No subsoiling; shallow Rome harrowing.
3. Subsoiling; deep mouldboard ploughing and harrowing.
4. Subsoiling; shallow Rome harrowing.

The subsoiler with four tines spaced 2 ft. apart penetrated to 18 in. when pulled by a TD 18 crawler tractor. Where the subsoiling was done a second time the tines were set to run between the first set of vertical cuts, but due to the heavy nature of the work, it was not always possible to make the second cuts exactly between the first set. The mouldboard plough penetrated between 9 and 12 inches, while the Rome harrow worked the soil to a depth of 5 to 7 inches. A satisfactory seed-bed was produced by mouldboard ploughing followed by Rome harrowing twice, or by three harrowings without previous ploughing: sugar cane was planted across the bed width, in rows 6 ft. apart, two weeks after the mechanical cultivations had been completed. Germination was good, and the percolation experiment was made when the cane was about 2 ft. high.

Experimental Technique

A long marking pin was placed in the centre of each field drain bordering an experimental plot. The horizontal distance between two adjacent drain centre-pins was measured and divided into six equal

parts, by a line of five pins to mark the divisions. The middle pin was thus the bed centre, although the highest point of the convex-shaped bed was sometimes slightly off-centre.

The depth of the drain on each side of the bed was measured with a Dumpy level and also the depth, at each of the five positions marked on the bed, to which a hole would have to be sunk so that the bottom of each

TABLE 1. *Depths of Boreholes, Depth of Drain Water, and Horizontal Distances of the Holes away from the Drain Waterline*

Cultivation treatment (see p. 351)	*Depth of drain water*		*Distance of holes from drain waterline*						*Depths of holes*					
			Outside		*Inter-mediate*		*Bed centre*		*Outside*		*Inter-mediate*		*Bed centre*	
	ft.	*in.*	*ft.*	*in.*	*ft.*	*in.*	*ft.*	*in.*	*ft.*	*in.*	*ft.*	*in.*	*ft.*	*in.*
A1	2	4	2	3	8	5	14	6	2	8	3	5	3	6
A2	2	7	2	8	8	10	15	0	2	10	3	4	3	9
A3	2	8	2	6	8	9	15	1	2	11	3	8	3	8
A4	2	7	1	11	8	3	14	8	2	10	3	3	3	3
B1	2	1	2	2	8	5	14	8	2	5	3	3	3	3
B2	2	5	2	5	8	8	14	11	2	7	3	1	3	1
B3	2	7	2	2	8	5	14	8	2	9	3	4	3	6
B4	2	4	2	3	8	7	14	11	2	9	3	1	3	2
C1	2	5	2	8	8	9	14	11	2	6	3	3	3	4
C2	2	8	2	2	8	3	14	5	2	11	3	3	3	4
C3	2	8	2	6	8	9	14	11	3	0	3	5	3	7
C4	2	5	2	0	8	5	14	10	2	6	2	11	3	2

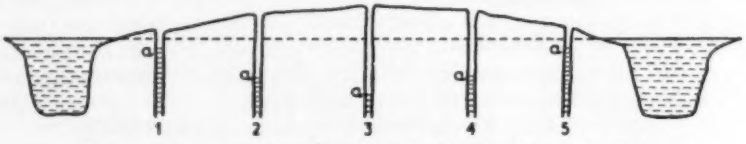

FIG. 1. *Diagrammatic vertical section through a line of boreholes across a bed*

1 and 5: outside holes
2 and 4: intermediate holes
3: bed centre hole

hole would be on the same horizontal level as the bottom of the shallower drain. (Adjacent drains were seldom the same depth.) These holes were carefully sunk using a 2-in. auger, and the depth measured by using a half-inch diameter measuring rod. A duplicate set of holes was similarly sunk 30 ft. farther along the bed, in each of the twelve plots.

The drains were then filled with water from a high-level canal, to just above the edges of the beds. Since all the infield drains were linked together, it was only necessary to note the level of the water at one convenient point, after which the level was maintained at this point by twice-daily additions of water, to ensure that the same level was maintained in all the drains throughout the whole period of the experiment.

When the water in the drains reached the required level, the distance from the water line to each of the holes at the side of the bed was care-

fully measured. This horizontal distance varied, as the beds were not all symmetrical. Table 1 gives the depths of the holes in each cultivation treatment plot, and the horizontal distance from each hole to the waterline at the bed edge, and also the depth of water in the shallower drain adjacent to the experimental plot, opposite the line of auger holes. The figures are averages for similarly placed holes of the two replicates. Fig. 1 shows how this was done and explains the terminology used to designate each position.

Measurement of Percolated Water

A period of six hours elapsed before the first measurement of percolated water in the holes was made. Placing a level across the top of the hole, the half-inch diameter measuring rod was pushed down the hole until the water-level (*a* in Fig. 1) showed on the bottom of the rod. Subtracting this measurement from the previously known depth of the particular hole gave the true depth of the percolation water. This method of measurement successfully overcame the practical difficulties normally encountered where loose soil generally fills the bottom few inches of an auger borehole after any length of time.

Results

Tables 2–4 show the depth of water which had percolated into the boreholes in each of the three positions after the water had been in the drains for 6, 24, 48, and 72 hours.

TABLE 2. *Average Depth of Percolated Water (in inches) in* OUTSIDE *Boreholes after Various Lengths of time*

Cultivation treatment (*see p. 351*)	*Time since start of percolation experiment*			
	6 hours	*24 hours*	*48 hours*	*72 hours*
A1	17	20	21	24
A2	8	16	20	26
A3	29	31	30	31
A4	24	28	28	28
B1	24	25	25	25
B2	19	21	24	26
B3	28	29	29	30
B4	23	24	24	25
C1	0	6	25	26
C2	20	23	24	28
C3	23	27	29	30
C4	13	15	18	22

Movement of Water through the Bed

Tables 2–4 show the great variation in the rate of percolation of water through the bed, and Table 4 is of special interest in this respect. Very rapid percolation into the outside holes in any of the experimental plots, which were only 2 to 3 ft. from the waterline, was to be expected, but one would also expect different rates of percolation to show up in the intermediate holes, as a result of the different cultivation techniques,

and this is indeed shown clearly in Table 3. Seeing that the depth of water in the bed centre hole (Table 4) is a measure of horizontal water percolation in the middle third of the bed, the importance of this measurement becomes evident.

TABLE 3. *Average Depth of Percolated Water (in inches) in* INTERMEDIATE *Boreholes after Various Lengths of Time*

Cultivation treatment (see p. 351)	*Time since start of percolation experiment*			
	6 hours	*24 hours*	*48 hours*	*72 hours*
A1	6	10	11	12
A2	14	17	16	17
A3	9	19	20	24
A4	5	13	14	18
B1	4	6	11	14
B2	3	10	13	21
B3	15	19	21	25
B4	14	19	21	22
C1	0	5	9	10
C2	8	13	18	21
C3	22	26	25	26
C4	17	17	22	22

TABLE 4. *Average Depth of Percolated Water (in inches) in* BED-CENTRE *Boreholes after Various Lengths of Time*

Cultivation treatment (see p. 351)	*Time since start of percolation experiment*			
	6 hours	*24 hours*	*48 hours*	*72 hours*
A1	10	13	14	16
A2	14	16	14	15
A3	14	18	19	19
A4	7	12	13	12
B1	4	7	11	20
B2	7	11	14	19
B3	16	19	23	26
B4	2	6	8	11
C1	2	4	4	8
C2	½	5	8	13
C3	11	18	24	25
C4	13	16	18	25

Table 5 shows the distance below the drain water-level down to which the soil in the middle third of the bed remained unsaturated after various time intervals. It also shows the height of the soil surface at the bed centre above the drain water-level, this being of interest here in emphasizing varying degree of bed convexity in each plot.

From the above it appears probable that had the time interval in this experiment extended beyond 72 hours, a situation would have been reached, possibly in about four days more, where the whole of the soil would have been saturated up to the drain water-level throughout the whole width of the bed in most of the plots.

Discussion

Normal Method of Irrigation

Although cane fields in British Guiana are occasionally flooded for 72 hours, with no apparent detrimental effect on the cane, the general opinion (and the author's) is that 48 hours under water is sufficient for irrigation purposes. Normally water flows into the field by gravity, or is pumped, until the highest point inside the field is a few inches under water.

TABLE 5. *Average Depth of Unsaturated Soil (in inches), at the Centre of the Bed, below the Drain Water-level, after Various Time Intervals*

Cultivation treatment (*see p. 351*)	*Time since start of percolation experiment*				*Height of soil surface above drain water-level*
	6 hours	*24 hours*	*48 hours*	*72 hours*	
A1	18	15	14	12	14
A2	18	15	17	16	14
A3	18	14	13	13	12
A4	24	19	18	19	8
B1	21	18	14	5	14
B2	22	19	15	10	8
B3	28	12	8	5	11
B4	27	22	20	17	10
C1	27	25	25	21	11
C2	32	27	24	19	7
C3	21	14	8	7	11
C4	16	13	11	4	9

The three main disadvantages of this system are:

(*a*) The excessive quantity of water used for each irrigation. The volume of water used in one irrigation is estimated as equivalent to 9 inches of rainfall, and when irrigation is completed, the excess water is released into the main drainage channels and is either lost to the sea or has to be pumped back into the estate high-level canals; either system shows inefficient use of water. Although most sugar estates have large water-conservancy schemes, there are times when irrigation has to be restricted or stopped for lack of water, with the result that the growth of the cane is also restricted [1]. (In the east coast district of Demerara during the prolonged dry season of 1958, irrigation had to be stopped completely on some estates for lack of water.)

(*b*) Exchangeable bases are leached from the soil, which causes land used for sugar-cane cultivation to become highly acidic [2], whereas new land taken into cane cultivation is often neutral or slightly alkaline in reaction. (The fertilizers applied to sugar cane, especially ammonium sulphate, may also make the soil acid.) High acidity can give rise to aluminium toxicity [3], and such soils readily fix phosphate [4], often resulting in poor responses to applied phosphate.

(*c*) Soil structure is sometimes seriously damaged, which reduces the number of successful ratoon crops. Damage is especially likely on the heavy clay soils which make up more than half the sugar-growing area.

Suggested Modified System

The results of these investigations suggest an alternative to flood irrigation. Table 6 shows the depth of soil in the centre of the bed, below the drain water-level, which was not saturated after 48 hours. The differences related to the different mechanical cultivation techniques employed in each plot are compared.

TABLE 6. *Average Depth of Unsaturated Soil (in inches) in the centre of the Bed, below the Drain Water-level, after 48 hours*

Cultivations across the bed (subsoiling to 18 in.)	*Cultivations along the bed*			
	No subsoiling		*Subsoiling to 18 in.*	
	(1) *Deep ploughing*	(2) *Shallow ploughing*	(3) *Deep ploughing*	(4) *Shallow ploughing*
No subsoiling (A)	14	17	13	18
Once subsoiling (B)	14	15	8	20
Twice subsoiling (C)	25	24	8	11

From that table, the following points emerge:

1. Subsoiling will increase percolation of water only if it is done across as well as along the beds.
2. Deep ploughing with the mouldboard type of plough allows water to percolate more than with shallow ploughing.
3. Water percolated most rapidly throughout the bed when subsoiling both along and across the bed, *and* mouldboard ploughing to a greater depth, were done.

The suggested modified irrigation system assumes three conditions. First, that the cultivation techniques most favourable to rapid moisture movement in the soil (as indicated in 3 above) are employed. Secondly, that cane to be irrigated will have a rooting depth of at least 1 ft. 6 in., and will be able to utilize moisture from a water table which is at this depth. Thirdly, that 48 hours is the longest permissible time for submerging the cane.

Instead of the normal system of allowing water completely to cover the highest point inside the field, the suggested method would be to flood the field to a height 10 in. below the highest point, and to leave the water at this level for 48 hours, so as to allow the water table to rise to within 1 ft. 6 in. of the soil surface at its highest point.

The Advantages of the New System

The main advantage of such a system would, of course, be the economy of water, for in practice the height of water necessary to achieve the desired results would not be much different from that used in this experiment, but it will naturally depend upon the shape of the beds and the topography of the particular field. (The highest point of the field used in this experiment was only 1 ft. 2 in. above the drain water-level.) With the irrigation water at the height of 10 in. below the highest

point in the field, probably only 2 to 3 ft. of cane row at each side of the bed would be under water. The soil structure is likely to be damaged less than through complete waterlogging. Similarly the leaching of plant nutrients from the topsoil would be less.

This modified system of irrigation is estimated to require only 25 per cent. of the amount of water used in a normal irrigation at present. This estimate is based on bed widths of 36 ft., but with the narrowest beds found in British Guiana cane cultivation (about 12 ft.), the saving in water would still be approximately 50 per cent.

There would also be corresponding savings in the cost of pumping irrigation water into the fields, and more land could be irrigated in a given time with the same pump capacity, so that the suggested method would make the system of irrigating sugar cane in British Guiana much more efficient.

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(*Received 4 August 1960*)

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JOURNAL OF THE BRITISH SOCIETY OF ANIMAL PRODUCTION

Contents of Volume 3, Part 3, October 1961

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ARMSTRONG, R. W., and CAMERON, A. E. Hexoestrol implantation of Blackface wether lambs.

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